UNCLASSIFIED

AD NUMBER

AD894935

NEW LIMITATION CHANGE

TO

Approved for public release, distribution unlimited

FROM

Distribution authorized to U.S. Gov't. agencies only; Test and Evaluation; 12 JUL 1972. Other requests shall be referred to Naval Rework Facility, Jacksonville, FL 32212.

AUTHORITY

NAVAIREWORKF ltr, 15 Nov 1974

THIS PAGE IS UNCLASSIFIED

1473

(9) Final rept.,

(10) Bernard W./Boisvert
Henry M./Sunderson

(11) 30 Mar 72

(12) 393p.

AD894935

NAVAL AIR REWORK FACILITY
POSSUMUS
JACKSONVILLE

(6)

20th DOD CONFERENCE
on
NONDESTRUCTIVE TESTING

(20th)

10–12 NOVEMBER 1971.

(407 417)

Per H. M. Gundersen (8/942-2164):
Distribution limited to U.S. Gov't. agencies only;
Test and Evaluation; 13 JUN 1972. Other requests
for this document must be referred to NAVAL AIR
REWORK FACILITY, Code 340,
Jacksonville, Fla. 32212.

A Healy
13 JUN 1972

ACCESSION for	
CFSTI	WHITE SECTION ☐
DDC	BUFF SECTION ☑
UNANNOUNCED	☐
JUSTIFICATION	
BY	
DISTRIBUTION/AVAILABILITY CODES	
DIST.	AVAIL. and/or SPECIAL
B	

407417

Naval Air Rework Facility

Jacksonville, Fla.

Keynote speaker discussing conference p`ans.

Left to Right: Bernard W. Boisvert, Steering Committee Chairman; Rear Admiral D. K. Weitzenfeld, Vice Commander, Naval Air Systems Command; and Captain A. J. Yates, Commanding Officer, NAVAIREWORKFAC JAX.

FOREWORD

We are happy that you were able tc attend the 20th DOD Conference on NDI at Jacksonville, Florida. You and the other 157 persons attending certainly made our Conference successful.

We wish to thank Rear Admiral D. K. Weitzenfeld, Vice Commander of the Naval Air Systems Command, for his excellent and dynamic Keynote Address. His interest and attendance at the first morning session of the Conference motivated speakers and listeners alike. We appreciate the warm welcome extended by Captain A. J. Yates of the Naval Air Rework Facility, Jacksonville, to all attendees.

Our thanks also go out to Mr. Bernard W. Boisvert, Steering Committee Chairman, for his able leadership. The entire Steering Committee is to be commended for its efforts in selecting interesting and informative problems and papers for presentation. By sharing the discussion leadership of each session, the Steering Committee made an additional contribution to assure a successful Conference.

Last, but by no means least, we thank Mrs. Betty G. Prim and the other ladies of the NAVAIREWORKFAC JAX for their assistance and administrative arrangements which helped to move the Conference to a smooth and successful conclusion.

We all extend our best wishes to a successful 21st Conference.

Henry M. Gundersen

HENRY M. GUNDERSEN
Host Chairman
Naval Air Rework Facility
Jacksonville, Florida 32212

TABLE OF CONTENTS

PURPOSE OF DEFENSE CONFERENCES ON NDT

SCOPE

The coordination of nondestructive testing and inspection of materials and assemblies within the Department of Defense.

OBJECTIVES

1. To provide for effective dissemination of information pertaining to nondestructive testing methods and applications among members and their respective Department of Defense establishments.

2. To provide a forum for the attack and solution of selected problems of the military by the utilization of their knowledge, skills, and experience of specialists in the Department of Defense.

3. To encourage, where applicable, uniform practices in the application of nondestructive testing methods.

FUNCTIONS

1. Organization of periodic DOD Conferences on nondestructive testing which will provide a forum for presentation of significant testing and inspection problems and technical papers on new methods or techniques.

2. Evaluation at conferences of problems and proposed solutions. The steps which are likely to be taken are:

a. Analysis of the problems in terms of materials, design, engineering, production, inspection, and testing history. Such an analysis may be only fragmentary before presentation at the conference, but should be as complete and detailed as possible before suggested solutions are sought.

b. Presentation of problems at the conferences as a whole or to a conference panel composed of qualified nondestructive testing and inspection personnel.

c. Communication between those posing the problems and those offering solutions, or offering to provide assistance in the solutions, starts at the conference. Once communication has been started, liaison between the parties involved proceeds at their discretion but in any case without further channeling through the conference.

d. Possible avenues of attack on problems will be reported to all conferees - orally at the conference and recorded in the proceedings. Periodically, the degree of success experienced with previous problems will be reported upon.

3. Development of format for the "Conference Proceedings" resulting from each DOD conference on nondestructive testing. Issuance and distribution shall be responsibility of the host establishment.

4. Compilation and distribution of useful information such as:

Individuals by name and organization, address, skills and knowledge, and willingness to advise others.

5. Encouragement of personal professional contacts with recognized nondestructive testing experts who can be called upon at will.

ORGANIZATION

1. Members - Active military personnel and Civil Service employees of the Defense Establishment concerned with nondestructive testing, inspection, or evaluation, who have confidential security clearance.

2. Officers - A Steering Committee of not less than four (4), or not more than nine (9); four of which shall be elected yearly for a 2-year term by a majority of the Conference. This committee will serve to receive and transmit information, to act as a steering group to plan conference, and will elect a senior member of the committee to be the chairman.

3. Meetings - The conference shall meet at least once a year at various establishments, as agreed upon between representatives of an establishment and the Steering Committee. The presiding officer at such meetings shall be the Steering Committee Chairman. Individual session chairman can be appointed.

LOCATIONS AND DATES

OF PREVIOUS CONFERENCES

Organizational Meeting	3-4 Oct 1951	Watertown Arsenal Watertown, Massachusetts
2nd Conference	23-24 Jan 1952	Frankford Arsenal Philadelphia, Pennsylvania
3rd Conference	19-20 Nov 1952	U.S. Naval Gun Factory Washington, D. C.
4th Conference	17-18 Mar 1954	Army Res. and Dev. Labs Fort Belvoir, Virginia
5th Conference	16-17 Mar 1955	Naval Ordnance Plant Indianapolis, Indiana
6th Conference	9-10 Apr 1956	Detroit Arsenal Centerline, Michigan
7th Conference	19-20 Feb 1957	U.S. Naval Ordnance Test Sta. China Lake, California
8th Conference	4-5 Dec 1957	SAAMA, Kelly Air Force Base, Texas
9th Conference	15-16 Oct 1958	Army Ballistics Missile Agency Redstone Arsenal, Alabama
10th Conference	6-7 Oct 1959	Naval Air Material Center Philadelphia, Pennsylvania
11th Conference	13-15 Sep 1960	OCAMA, Tinker Air Force Base, Oklahoma
12th Conference	28-30 Aug 1961	Army Natick Laboratories Natick, Massachusetts
13th Conference	25-27 Sep 1962	Naval Ammunition Depot Concord, California
14th Conference	25-27 Aug 1964	Robins Air Force Base, Georgia

15th Conference	4-6 Oct 1966	U.S. Army Mat'ls Res. Agency Watertown, Massachusetts
16th Conference	26-28 Sep 1967	U.S. Naval Ordnance Laboratory White Oak, Maryland
17th Conference	18-20 Sep 1968	USAF-ATC, Randolph AFB, San Antonio, Texas
18th Conference	29-31 Oct 1969	Defense Contract Administration Svcs Region, San Francisco, CA
19th Conference	4-6 Nov 1970	U.S. Army Mobility Equip. Command, St. Louis, Missouri

REAR ADMIRAL D. K. WEITZENFELD

KEYNOTE ADDRESS
ABSTRACT

The original NDT technique - the eyeball method - has been in use for thousands of years. The more exacting techniques used during the 20 years your organization has been active are the five basic techniques of: (1) X-ray, (2) eddy current, (3) ultrasonic, (4) magnetic particle, and (5) penetrant.

My observations will basically relate to naval aviation, although similar problems are experienced in all the military services. Of course, a pilot will sometimes be forced to leave his aircraft when a vital flight control component fails, which gives special emphasis to prevent failure. NDT methods have minimized the effort expended on several recent problems by avoiding total disassembly of aircraft components to perform an inspection for flaws.

I have been told that all the world's recorded knowledge up to 1940 was doubled again by 1960. This total knowledge was again approximately doubled by 1970. Our total knowledge is now four times that existing in 1940. Since the total knowledge will double approximately each 10 years, just imagine what the total amount and rate of acquisition will be in 20 or 30 years. It is proper to ask ourselves if NDT application to maintenance has kept pace with this vast increase in knowledge.

We have previously addressed ourselves to methods of finding a flaw after it has occurred. When an aircraft is examined and no faults found, it does not suggest that defects won't occur during the next flight. This somewhat negative result should be replaced with the positive findings indicating when a failure is likely to occur. How much more challenging it is to predict when a failure is likely to occur and prevent its occurrence! This idea is not new, as acoustic emission is one means now being explored for this prediction. This does not suggest that the traditional methods of NDT should be neglected, as the field maintenance man needs our best efforts to assure reliability of equipment and methods. We cannot afford to do less than our best.

The challenge I am giving you is positive. Search for the technique which will tell us: "This part will require attention on this date." The airlines are beginning to achieve this goal with about 90 percent of all maintenance being scheduled into the repair shop. Imagine a weapon which functions "as advertised" and which can be maintained on a scheduled basis. Let's all work toward this challenging goal!

Rear Admiral D. K. Weitzenfeld
Vice Commander
Naval Air Systems Command
Washington, D. C.

CAPTAIN A. J. YATES

WELCOME ADDRESS

Good morning, Ladies and Gentlemen:

As Commanding Officer of your host activity, the Naval Air Rework Facility, I bring you a warm welcome to the "Bold New City" of Jacksonville and to this 20th Annual Department of Defense Conference on Nondestructive Testing.

NDT is an especially important subject for those of us engaged in depot level aeronautical maintenance. We must be ever alert for ways by which we can adapt to our business the techniques of nondestructive testing and thereby become more efficient. NDT procedures can insure the continued integrity of airframe and engine components without the necessity for costly disassembly. As you will hear in more detail from our attendees at this conference, these means of testing offer us the opportunity to be truly competitive and to accomplish our mission in as economical a manner as possible.

With the knowledge, skills, and experience of such nondestructive testing specialists as are in attendance, I am sure this forum will be a most profitable undertaking. You will be stimulated so that when you return to your regular place of employment, you will be able to enthusiastically implement fresh approaches to nondestructive testing methods and applications in your own work environment.

If, in any way, we of the Jacksonville Naval Air Rework Facility can assist you, please let us know. Again I would say Welcome, we are happy to have you with us. Thank you.

Captain A. J. Yates
Commanding Officer
Naval Air Rework Facility
Naval Air Station
Jacksonville, Florida 32212

FORMAL PROBLEMS

AND

PROBLEM COORDINATOR

SUMMARY REPORTS

PROBLEM #1

DETERMINATION OF INCIPIENT MELTING IN ALUMINUM ALLOY COMPONENTS

Duane O. Gustad
Ammunition Development and Engineering Laboratories
Frankford Arsenal
Philadelphia, Pa.

ABSTRACT

Solution heat treatment of certain aluminum alloys requires that the treatment temperature be only slightly below the eutectic melting temperature of the alloy. If the eutectic melting temperature of the alloy is exceeded, incipient melting occurs and the material is rendered brittle. Rosettes and heavy grain boundaries are manifestations of material that melted during solution heat treatment and resolidified during subsequent quenching. The as-cast structure in these areas is extremely brittle, and because of the nearly continuous grain boundary films, brittleness is imparted to the gross structure.

At present, the most reliable method of detecting the overheated condition is a destructive metallographic examination for rosettes and grain boundary melting. This method has proven to be a fairly reliable but time consuming quality control technique when applied on a random sampling basis for each heat lot of material. However, prior to instituting this test procedure, some assemblies containing overheated aluminum components got into the field and caused suspension of large quantities of ammunition. For these reasons, a non-destructive technique is needed to provide a fast, cheap method of inspection which could be applied as both a production quality control technique and for field screening of suspect ammunition.

INTRODUCTION

The general problem which I wish to present concerns the detection of incipient or eutectic melting in heat treated aluminum alloy components. Solution heat treatment of certain aluminum alloys requires that the treatment temperature be only slightly below the eutectic melting temperature of the alloy. The proximity of typical solution treating temperature ranges to eutectic melting temperatures of three common alloys is shown in Table I. If the eutectic melting temperature of the alloy is exceeded, incipient melting occurs and the material is rendered brittle and nonsalvageable. Rosettes and heavy grain boundaries as depicted in the photomicrographs shown in Figure 1 are manifestations of material that melted during solution heat treatment and resolidified during subsequent cooling. These areas of localized melting represent an as-cast structure which is extremely brittle. As the degree of overheating increases, the grain boundary film becomes nearly continuous and brittleness is imparted to the gross structure.

TABLE I

Alloy	Solution Treating Temp., F	Eutectic Melting Temp., F
2014	925 to 945	950
2017	925 to 945	955
2024	910 to 930	935

PROBLEM

The specific problem I wish to present is concerned with detecting incipient melting in a cartridge housing for the fin assembly of an 81mm mortar shell shown in Figure 2. This component is a 2014 aluminum alloy die forging purchased to ASTM Specification B-247. The mechanical property requirements are 40,000 psi minimum yield strength at .2% offset and 7% minimum elongation. The cartridge housing shown in Figure 3 depicts the failure experienced when an overheated cartridge housing is fired.

DISCUSSION

For those of you not familiar with this item, let me explain the ignition sequence. During assembly, an ignition cartridge is placed in the internal cavity of the cartridge housing and a percussion primer is screwed into the base of the fin. The proper number of propellant bags, depending on range desired, are attached to the increment holder. When the mortar round is dropped in the mortar tube, the primer strikes the firing pin at the bottom of the tube which ignites the ignition cartridge which in turn ignites the propellant charge through the holes in the cartridge housing. The pieces shown in Figure 3 were emptied from the mortar tube after firing a mortar shell which had an overheated aluminum cartridge housing. The impact load experienced by the cartridge housing during ignition completely fractured the housing. The mortar shell was then propelled from the mortar tube minus the fin assembly. The lack of fin stabilization resulted in the short round.

PRESENT INSPECTION METHOD

Mechanical property tests conducted on components which failed due to overheating, show that in some instances, the ductility as measured by percent elongation during tension testing is slightly below minimum requirements; however, most often the overheated condition is not detected by the conventional tension test. At present, the most reliable method of detecting the overheated condition is a destructive metallographic examination for rosettes and grain boundary melting. This testing procedure is now a specification requirement for manufacture of the fin assembly. Under this procedure, two cartridge housing forgings must be selected from each heat treat batch, or each

5000 pieces if heat treatment is performed on a continuous basis, for microscopic examination. The specimens cut from these two cartridge housings are then polished and etched for microscopic examination at a minimum magnification of 500 diameters. Overheating as evidenced by the presence of rosettes or incipient melting at the grain boundaries in either sample is cause for rejection of the solution heat treat batch represented by the samples. This inspection method has proven to be a reliable but time consuming quality control technique.

EXPERIMENTAL STUDIES

Non-destructive testing techniques which have been tried experimentally to detect the overheated condition are the conductivity test using a Sigmatest "T" type portable eddy current instrument and the eddy current differential type test using a Model QC-61-5 multitest instrument. Both of these instruments are manufactured by Automation Industries. The conductivity test was not sufficiently sensitive to detect overheating; whereas, the sensitivity of the QC-61 instrument had to be set so high that chemical variations from lot to lot caused erroneous results. The QC-61 instrument used two remotely located coils. A standard cartridge housing of known quality was placed in the first coil. Screening of cartridge housings of unknown quality was performed in the second coil which resulted in a direct comparison between the standard and unknown cartridge housings. So long as the instrument was set-up using standards from a given heat of aluminum, the eddy current technique was sufficiently discriminating to screen out overheated housings; however, each change in heat lot of material required establishment of new standards. Obviously, the constant change in standards with each lot of material is not satisfactory for production or field type testing.

Prior to instituting the microstructure test procedure as a specification requirement, many lots of 81mm mortar shell got into the field and were subsequently suspended from usage. Inspection of this material presents an additional problem because of the configuration of the 81mm mortar round. For example, the coils used with the QC-61 instrument could not be used for assembled cartridge housing since there would be no way to get the cartridge housing into the coil. Therefore, a non-destructive technique is needed to provide a fast, cheap and reliable method of inspection which could be applied to both cartridge housing components as a production operation and cartridge housings already in the field as 81mm mortar round assemblies.

Commanding Officer
Frankford Arsenal
Bridge & Tacony Streets
Philadelphia, PA 19137
ATTN: Duane O. Gustad

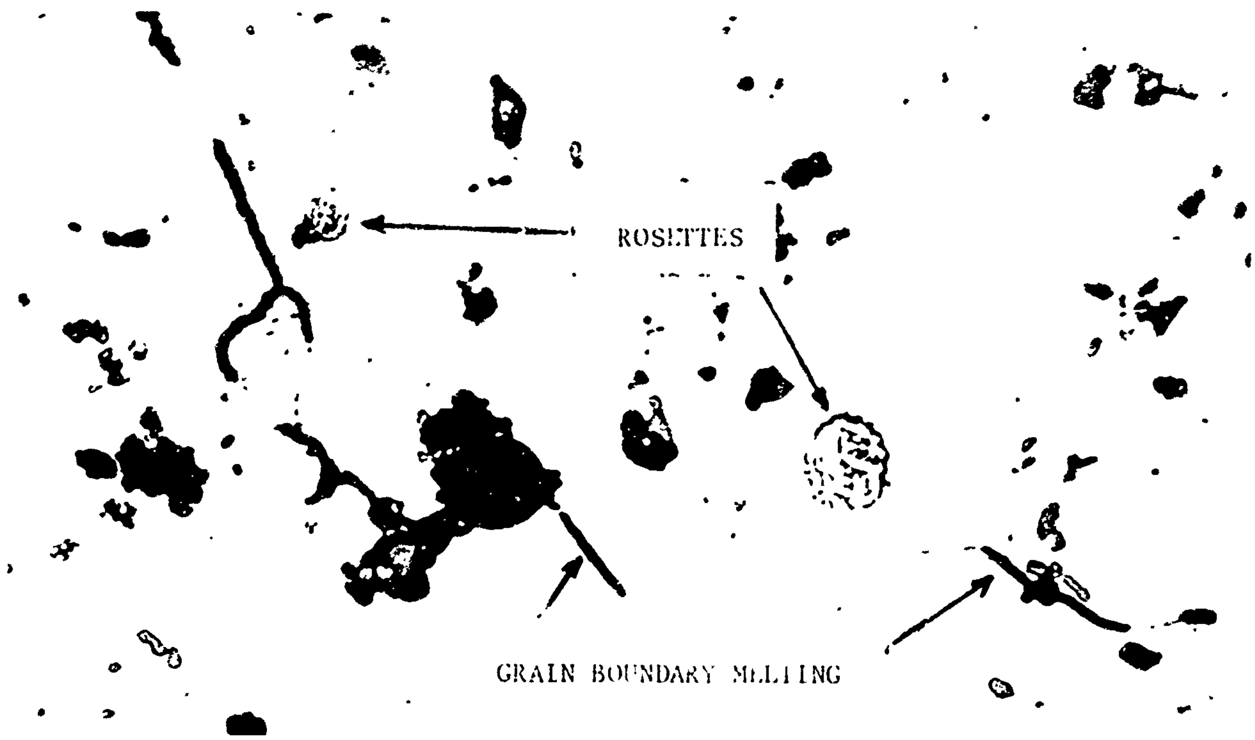


FIGURE 1 1000X

PHOTOMICROGRAPH SHOWING ROSETTES AND GRAIN BOUNDARY MELTING

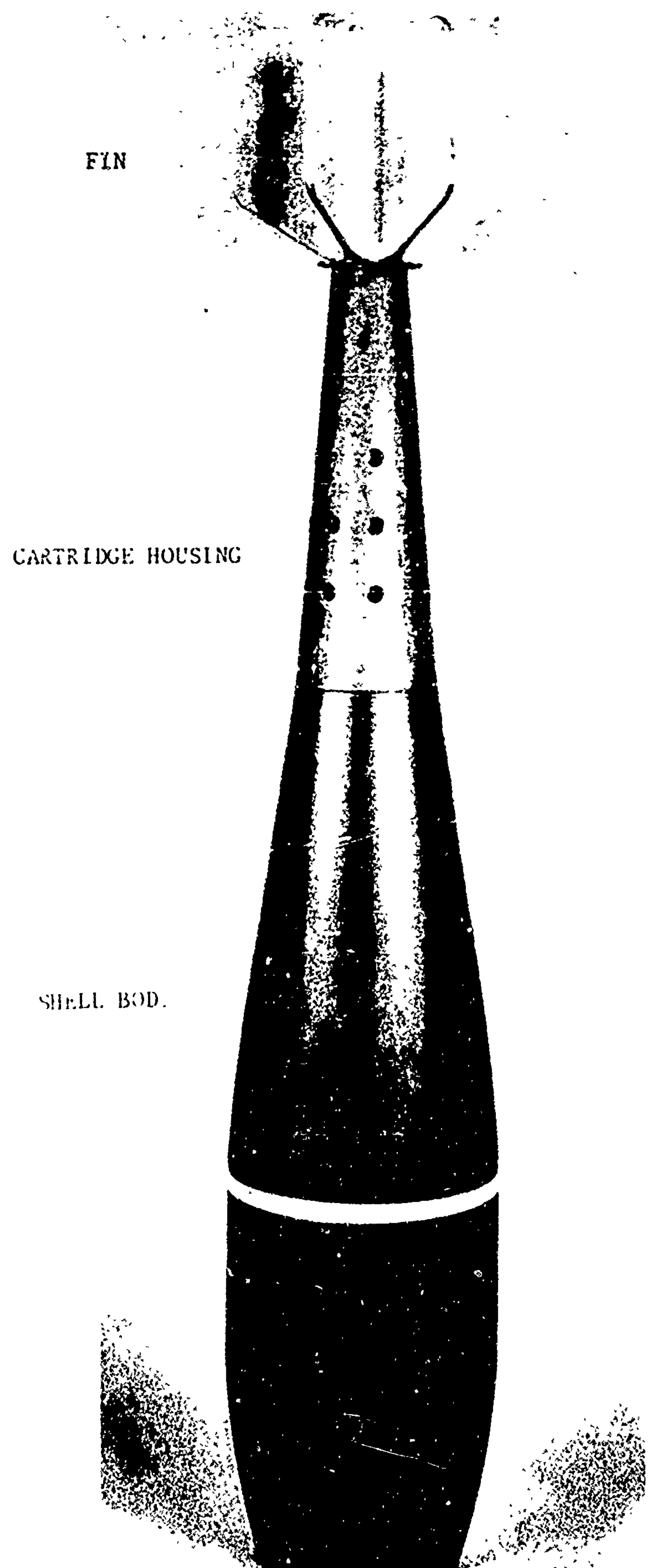


FIGURE 2 81MM MORTAR SHELL BODY AND FIN ASSEMBLY

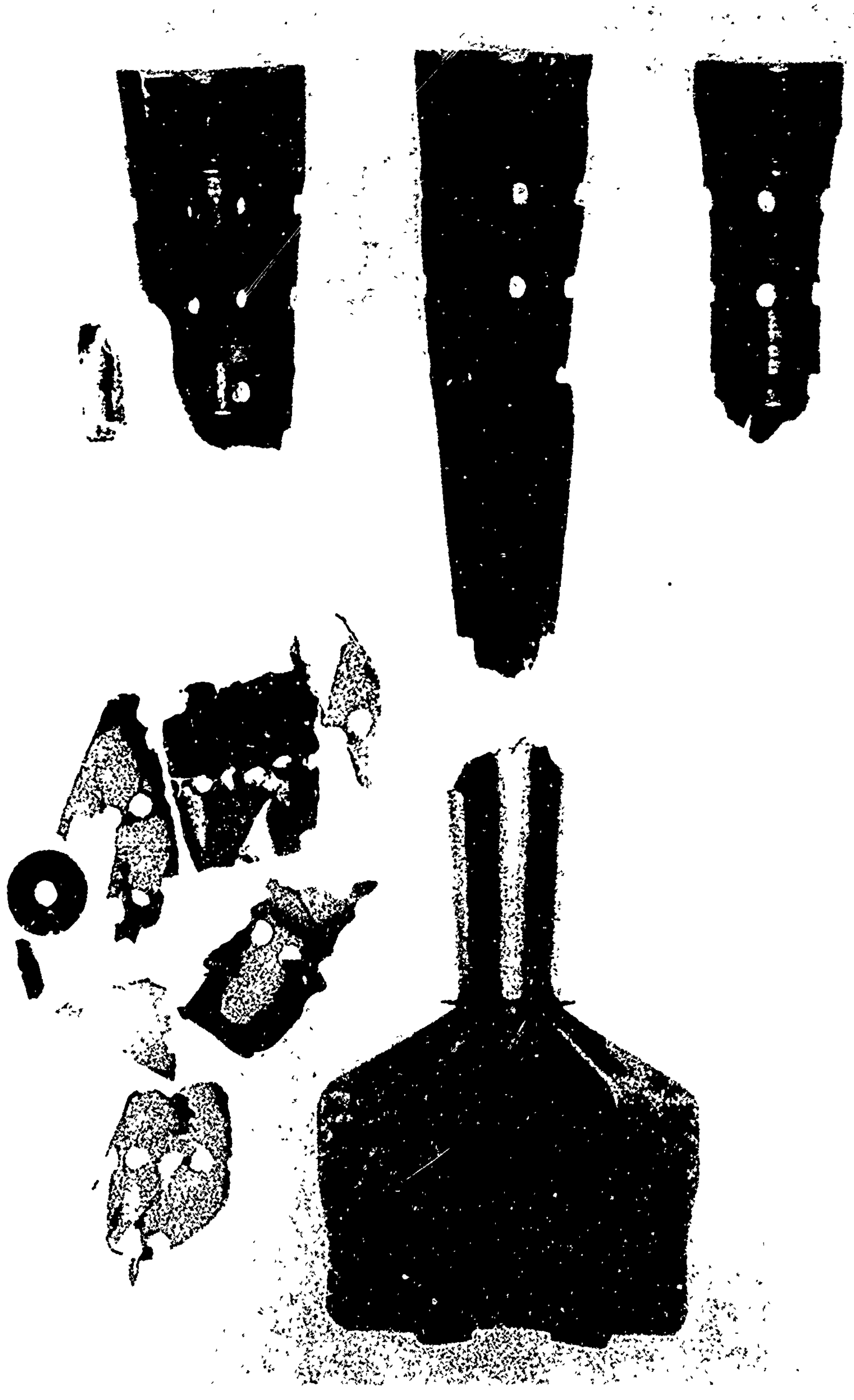


FIGURE 3 FIN ASSEMBLY SHOWING CARTRIDGE HOUSING FAILURE CAUSED BY INCIPIENT MELTING

SUMMARY REPORT OF PROBLEM NO. 1

DETERMINATION OF INCIPIENT MELTING
IN ALUMINUM ALLOY COMPONENTS

Domenic J. Molella
Problem Coordinator

PROBLEM:

Detection by nondestructive tests of overheating in 2014-T6 aluminum alloy material utilized in the 81 mm. mortar cartridge housing is desired. Overheating causes embrittlement of the aluminum due to incipient melting and the random formation of rosettes in the matrix and/or grain boundaries and formation of heavy grain boundaries.

SOLUTIONS RECOMMENDED:

1. David Stein, Picatinny Arsenal - Indicated that knowledge of the chemistry and heat number of each lot should be beneficial to aid in the solution.

2. Problem coordinator suggested utilization of computerized ultrasonic attenuation determination. Studies performed by Messrs. McEleney and Reid, AMMRC on the 2014-T6 aluminum indicated that above method can positively determine overheating. Copy of a report of these studies was furnished to Mr. Gustad by Mr. Charles Merhib, AMMRC.

3. Use of eddy current electrical conductivity and ultrasonic attenuation methods was also recommended by Mr. Stephen Hart, NRL.

4. Mr. Michael Stellabotte, NAVAIRDEVCEN, suggested two possible methods:

a. "Four-Point" probe for determination of electrical conductivity. Method is used by semi-conductor industry to measure absolute electrical conductivity.

b. "Electric Injection" technique, a method similar to magnetic perturbation technique, but for use on nonferrous materials as published by Southwest Research Institute.

5. Mr. Eugene Roffman, Frankford Arsenal, suggested utilization of thermocouple potentiometrics method as determined by millivoltage variations due to chemical or microstructural abnormalities.

6. Mr. Mark Weinberg, Picatinny Arsenal, suggested thermoelectrical, plus eddy current methods to positively pinpoint presence of detrimental microconstituents.

7. Captain G. H. Hill, Randolph Air Force Base, suggested use of infrared technique, which Air Force has used to determine heat damage in aircraft exhaust components.

8. Use of Ultrasonic Resonance Frequency Method was suggested by someone in the audience.

9. Mr. Emmett Barnes, Picatinny Arsenal, suggested use of nucleonic device to activate the copper and detect variation in copper which is a component of the eutectic microconstituent with a scintillator.

DOMENIC J. MOLELLA
Picatinny Arsenal
Dover, NJ

PROBLEM #2

By
M. S. Orysh
Naval Ship Engineering Center,
Philadelphia Division

NEED FOR METHOD OF NONDESTRUCTIVELY INSPECTING BOILER TUBES FROM THE INSIDE

The Naval Ship Engineering Center, Philadelphia Division needs a method for nondestructively inspecting tubes of supercharged boilers.

Figure 1 is a cross-sectional view of a typical supercharged boiler. The tubes of prime concern are the 160 tubes in the outer row. These tubes are made of carbon steel in accordance with Class G of MIL-T-16286. They have an outside diameter of 1 1/4 inches and a wall thickness of 0.095 inch. These tubes have two bends of 31 degrees and two of 45 degrees. The radius of each bend is 4 3/4 inches. The lower ends of these tubes are swaged to 1-inch outside diameter (0.095 inch wall) before they enter the convection header to reduce header size. The outer row tubes are joined by welding narrow baffle bars between the tubes. The important dimensions are:

from upper header to first bend:	approx. 11 inches.
between upper two bends:	approx. 9 inches.
between upper and lower bends:	approx. 45 inches.
between lower two bends:	approx. 12 inches.
from lowest bend to convection header:	approx. 21 inches.
total distance between the upper header and convection header:	98 inches

During the service life of the boilers, deposits build up on the interior (waterside) and on the exterior (fireside) surfaces of the tubes. The deposits may be either soft or hard and of varying lengths and thicknesses. In addition, pits and cracks develop on the inside (watersides) of the tubes. The pits are generally small in size and are scattered. With time, they increase in size and number. The cracks are small, narrow and invariably oriented parallel to the long axis of the tubes between the baffle welds in the bend regions. Therefore, they do not lend themselves to easy detection and measurement (see Figures 2 and 3).

The defects in Figure 2 are from 0.003 to 0.004 inches deep whereas those in Figure 3 are 0.017 to 0.020 inches deep. If not detected, they will propagate through the walls, cause a loss of feedwater and, eventually, the operational ability of the boiler.

The present method of inspecting boiler tubes is destructive, costly and time consuming. Twelve tubes of the 160-tube outer row are removed from the boiler, longitudinally sectioned and visually examined. The selection of tubes for the visual examination is based on the operational history of the boiler and is guided by the boiler inspector's experience with this type of unit. The number selected derives from a combination of tube failure history together with economical cost of tube replacement. The cost of removing and replacing the twelve tubes is estimated at $25,000 and the cost of replacing the 160 tubes is estimated at $200,000. The results of the visual examination determine if additional tubes should be replaced. It should be noted that the twelve-tube sample typically includes tubes which are found to be relatively free of detrimental defects.

We are seeking a method of inspecting the tubes in place which will enable us to determine when defective tubes should be replaced. The goal is to be able to measure cracks 0.010 to 0.030 inches deep in tubes either through the upper header or through the convection header. Other methods of examination have been studied or attempted. They include:

Optical (Borescope) - This technique permits the visual inspection of clean tubes in the straight lengths and in some bend areas. It may also locate pits and, with magnification, some small cracks. However, the presence of corrosion products in the defects tends to mask the true size of the defects.

Radiography - This technique was not sensitive enough to pick up the small-size defects.

Ultrasonics - A contractor attempted to develop a shear wave probe technique for the 1 1/4-inch OD tubes. He was unsuccessful because the signal was lost as the probe travelled through the bends. In the area of the bends, the tube cross-section changes from round to oval. Because of this change, it was not possible to maintain the sound beam at a constant incident angle to the inside surface in the bend area.

Ultrasonics (con't)	- In addition, the baffle-bar welds prohibited the reflection of the sound beam from approximately 1/3 of the circumference of the tubes in the area where many of the pits and cracks are known to occur.
Exo-electron emission	- This technique was unsuccessful because it cannot detect the small pits common to our problem.
Eddy current	- Was not considered because the magnetic flux lines will be severly altered by the baffle-bar welds attached to each tube.

To summarize, my Division needs a method of inspecting supercharged boiler tubes in place and from the inside of the tubes. The tubes may be coated externally and internally with deposits of varying lengths, thicknesses, and hardnesses. The desired method must permit us to determine the remaining wall thicknesses in the region of small pits and small narrow cracks. Finally, the method must be adaptable for use aboard ship.

Officer in Charge
Naval Ship Engineering Center,
Philadelphia Division
Philadelphia, PA 19112
ATTN: M. S. Orysh

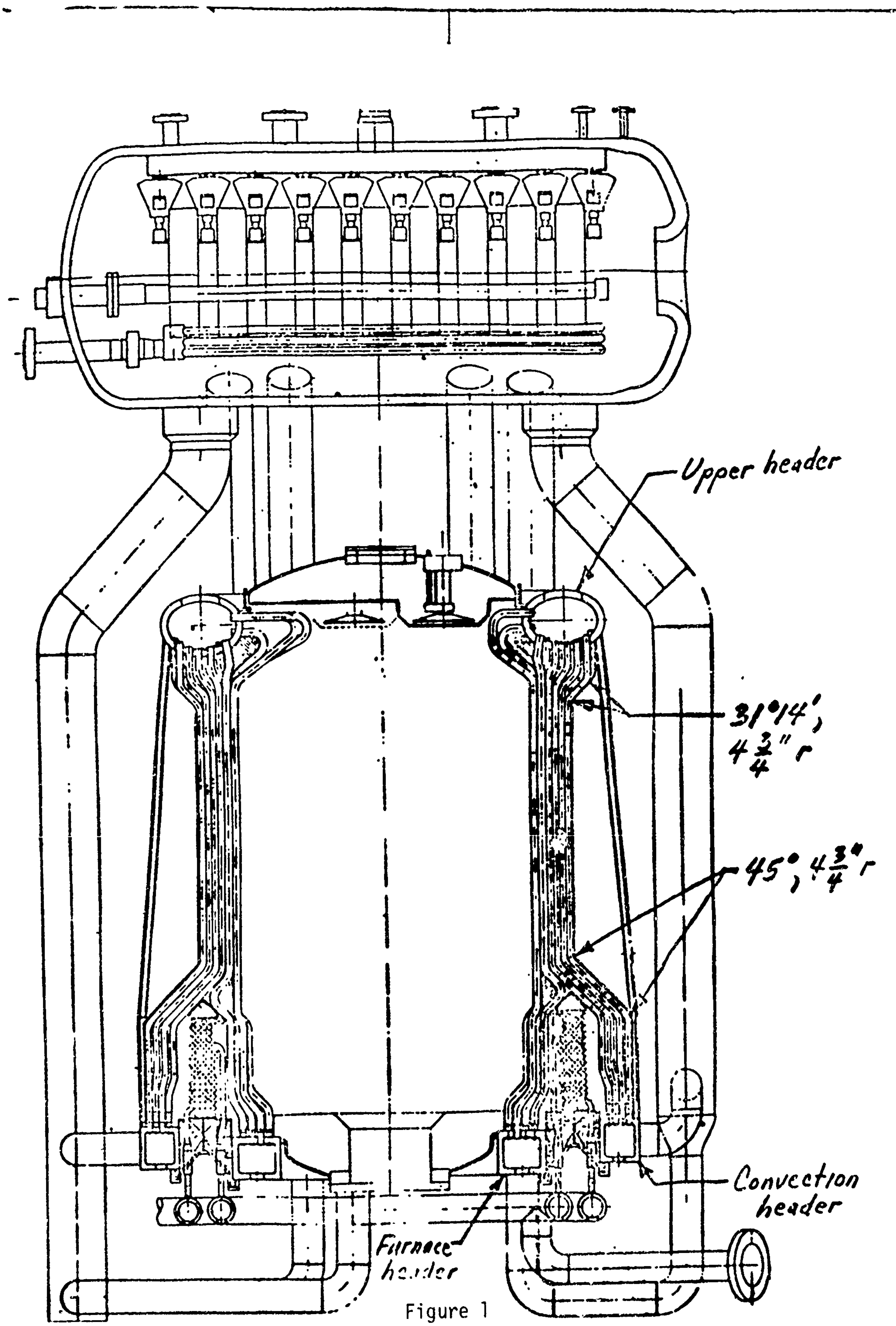
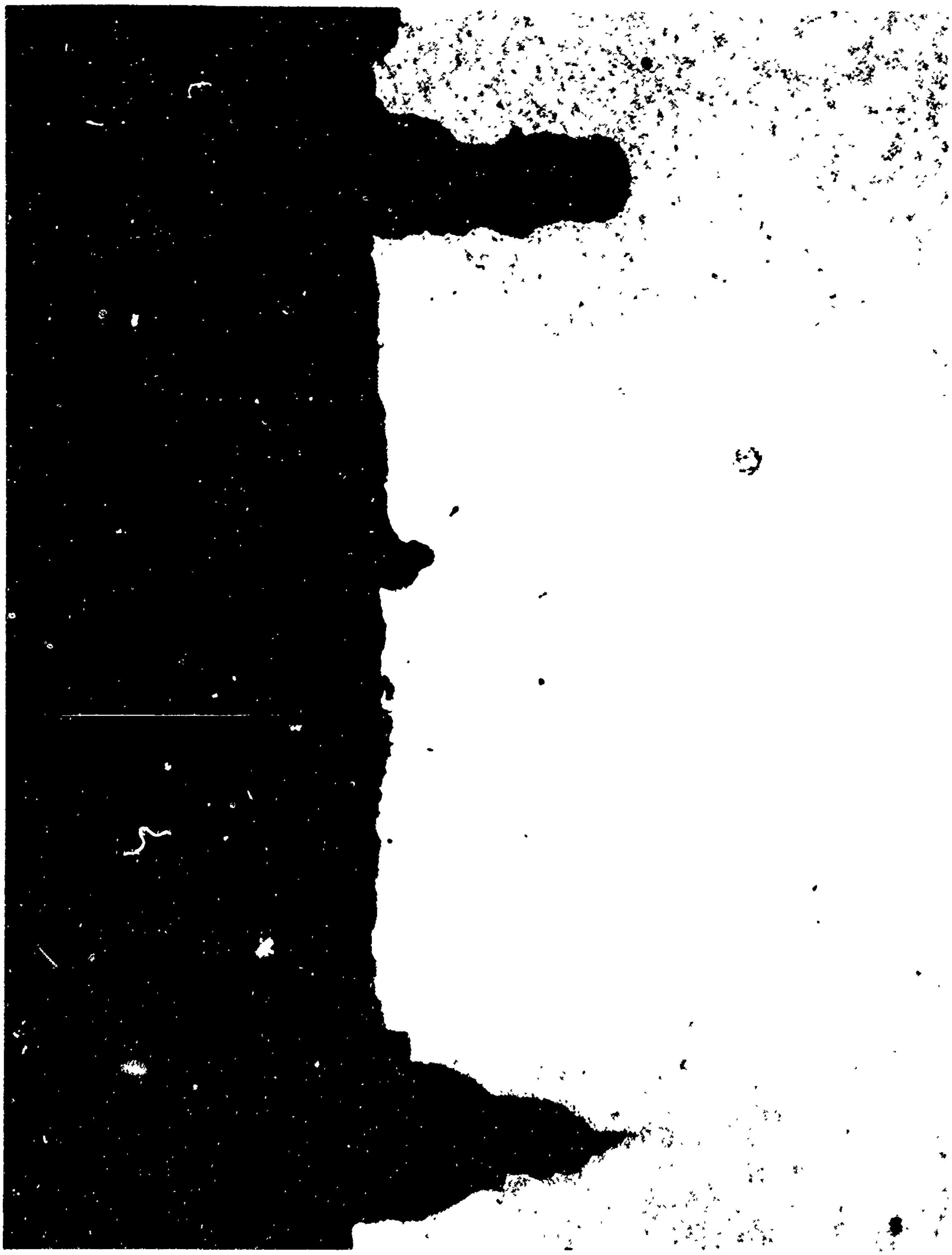

Upper header
31°14', $4\frac{3}{4}$" r
45°, $4\frac{3}{4}$" r
Convection header
Furnace header

Figure 1

50X

Figure 2



50X

Figure 3

SUMMARY REPORT OF PROBLEM NO. 2

NEED FOR METHOD OF NONDESTRUCTIVELY INSPECTING BOILER TUBES FROM THE INSIDE

D. M. Moses
Problem Coordinator

1. There were two approaches taken to provide potential solution to the problem of crack and pit evaluation in the boiler tubes. The first was to attempt to measure the depth of the existing cracks and pits. Two possible methods were suggested, eddy current and acoustical emission. Techniques of eddy current inspection for tubes have been developed by the Atomic Energy Commission. This technique utilizes a spring-loaded coil with a flexible coupling. The second eddy current method developed by Battelle Northwest utilizes a multi-coil probe. Each coil is separately activated, giving a read-out as each complete coil pass is completed. The probe is pushed forward an appropriate increment. The output from the coils is fed into a computer for printout.

2. The second suggestion was to place a microphone within the tube close to the ends, and apply internal pressure. Correlate the "cry" with depth of indication from known samples.

3. The second approach was to utilize the many methods of detecting cracks: visible penetrant, visual examination, and tracer elements. The important consideration here is cleaning the opening for entrance of the detecting material. Pressure application of Krypton-Nitrogen mixtures might do better than liquid penetrants. Evacuate the tube and "look" for traces of the Krypton. Record the pits and crack seams, laps found, and reinspect to determine propagation. Correlate this with limits for rejection developed for this parameter.

4. Visual inspection and visible dye-penetrant inspection can be accomplished by use of borescopes. Suggested techniques include fiber optics borescopes coupled to TV cameras. The fiber optics will maneuver the bends and the camera coupling will provide convenient and magnified images of the internal surface.

D. M. Moses
Defense Supply Agency
Alexandria, VA 22314

PROBLEM #3

By

W. H. Schoeller, Picatinny Arsenal

DETERMINATION OF STRUCTURAL STRENGTH OF M117A1E1 750# BOMB BODY

1. INTRODUCTION:

The bomb body to be evaluated is a component of the M117 series of general purpose bombs which were designed in early 1950. The bomb body which contains high explosive is designed for improved aerodynamic performance and accuracy in flight when released from most altitudes and air speeds. A conical fin assembly is bolted to the rear. The bombs are designed for either mechanical or electrical fuzing; consequently, they are equipped with nose and tail fuzes and boosters. Bomb body contains two lugs 14 inches apart for suspension on the aircraft. Effectiveness of the bomb depends upon the structural integrity of the bomb body. Stress analysis based on velocity of 800 ft/sec when impacted against a 3-foot reinforced concrete target indicates that the bomb body is subjected, theoretically, to 8860 g's maximum.

2. MANUFACTURE:

Body is made of resistance seam-welded 1027-1036 steel tubing (MIL-B-2530). Ogive is nosed in 3 forging operations and tail is forged in one operation. Forging temperature is 2400 to 2100°F. 1027-1036 steel inserts are welded to side wall and ring flange is welded to base. Body is about 48" long, 16" in diameter and 7/16" in wall thickness. Dimensions of the body and body assembly are shown on figures 1 and 2. A photograph of the body assembly mounted on rocket sled is shown in Figure 3. Body assembly is heat treated and stress relieved at 900°F for 30 minutes immediately after welding. It is then heat treated to meet certain minimum tensile and yield strengths, elongation and Brinell hardness.

3. DISCUSSION:

Although minimum mechanical properties are specified only the Brinell hardness is taken at the OD surface between the two welded inserts of each body. There is a direct relationship between hardness and tensile strength; however, no

direct relationship exists between hardness, yield strength and percent elongation. The Brinell hardness is only a surface hardness indication at a certain point. This does not guarantee that the same hardness exists throughout the wall over the entire bomb body. This is proven by the fact that even though the bombs meet the Brinell hardness requirements those made by certain manufacturers differ in structural characteristics. For example, some bodies break-up when impacted at velocities of less than 500 ft/sec and others do not break-up when impacted above 900 ft/sec.

Minimum specifications for bomb bodies in production phase are as follows: 105,000 psi tensile and 70,000 psi yeild strengths, 16% elongation and 217 Brinell hardness. Although not specified, Rocket Sled Impact Tests (RSIT) are conducted on a limited basis on production items and on an extensive basis on special and experimental bombs. The RSIT is used to evaluate structural integrity of high explosive loaded bomb body and also to evaluate sensitivity of various high explosives. Bomb body should not fracture when impacted at 800 ft/sec minimum velocity through a 3-foot reinforced concrete target. The RSIT are conducted at the Naval Weapons Center, China Lake, on the supersonic Naval Ordnance Research Track (SNORT). From mid 1967 to the present, 129 RSIT have been performed. The tests are very costly, e.g., $2,000 to $3,000 each test.

4. PRESENT TEST PROCEDURE:

a. Brinell Hardness

This test is performed on the production line on each body after heat treatment and after welding. Only one hardness reading is taken at OD surface between the two welded inserts. A specially designed Hardness Tester to accommodate the large diameter is utilized. Exact location where hardness is taken is indicated on drawings in Figure 2.

b. RSIT

The evaluation was conducted on the SNORT 4.1-mile-long dual-rail test track with a test assembly mounted on each rail so that two bombs could be set up simultaneously and tested sequentially (Figs. 3, 4 and 5). The bombs were

attached to track shoes by the bomb lugs and propelled to the desired target-impact velocity by a small monorail pusher sled using 5-inch HVAR rocket motors for propulsion. The starting position was such that it allowed the bomb to reach the required velocity and coast off the end of the track into the target. To protect the track from possible explosive damage, the target for one bomb was located 20 feet from the end of the track, and the target for the second bomb was located 35 feet from the end of the track. The number of motors used and the distance from the firing point at the end of the track were selected according to the desired velocity of the bomb as it left the end of the track. Since the aerodynamic drag of the pusher sled was greater than that of the bomb, there was ample separation between the two at target impact to preclude any impact interference from the sled. (However, the sled also coasted off the end of the track and was lost during each test.) Figure 5 shows two typical reinforced concrete targets and the dual-rail test track.

5. ROCKET SLED IMPACT TEST RESULTS

On some of the tests on production and experimental bomb bodies successful bomb penetration occurred with only slight damage (bulging) to the bomb (Figure 6). On other tests the bomb body split open and bulged (Figure 7) while on others the bombs detonated (fractured) (Figure 8).

6. THE PROBLEM

The problem is to evaluate by non-destructive tests (ndt) the structural integrity of the bomb body. The present methods of evaluation, i.e., Brinell and RSIT are either expensive or inadequate. Bomb body must have adequate strength to penetrate the reinforced concrete target without break-up so that it can be set off by fuzing after penetration; consequently, the ndt must be reliable enough to insure adequate structural strength. It also must be able to determine the mechanical properties at the critical ogive area.

Two manufacturers are currently producing a total of 35,000 bombs per month. However, this figure will drop to

approximately 10,000 per month after 1 January 1972. The ndt equipment can be portable or stationary with no limit on size and weight. A reliable ndt solution is urgently required for all bombs and projectiles manufactured currently and in the future.

Picatinny Arsenal
SMUPA RI-M
T.S.D Bldg 352
Dover, NJ 07801
ATTN: W. H. Schoeller

SUMMARY REPORT OF PROBLEM NO. 3 INCLUDED WITH SUMMARY REPORT OF PROBLEM NO. 4

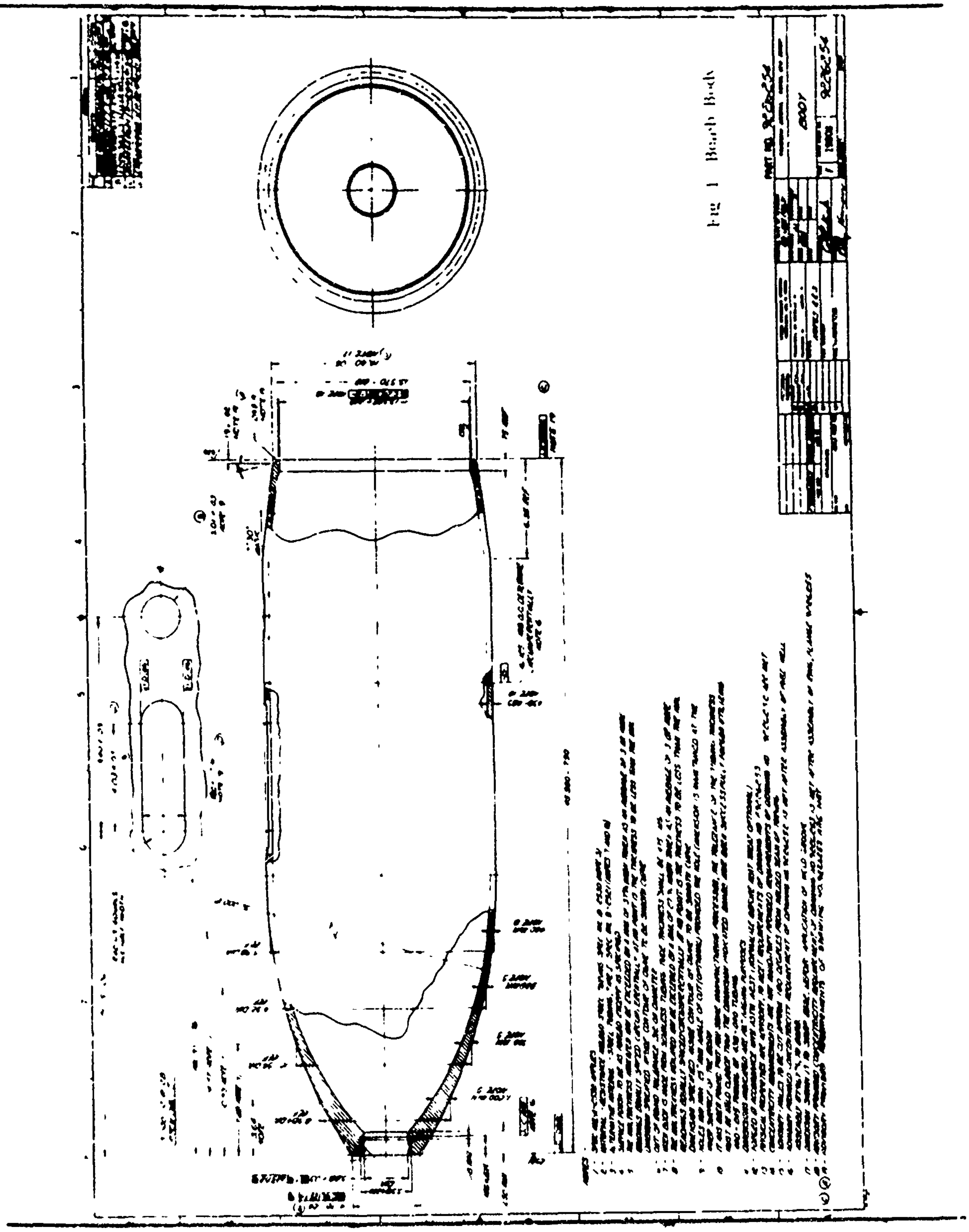


Fig 1 Bomb Body

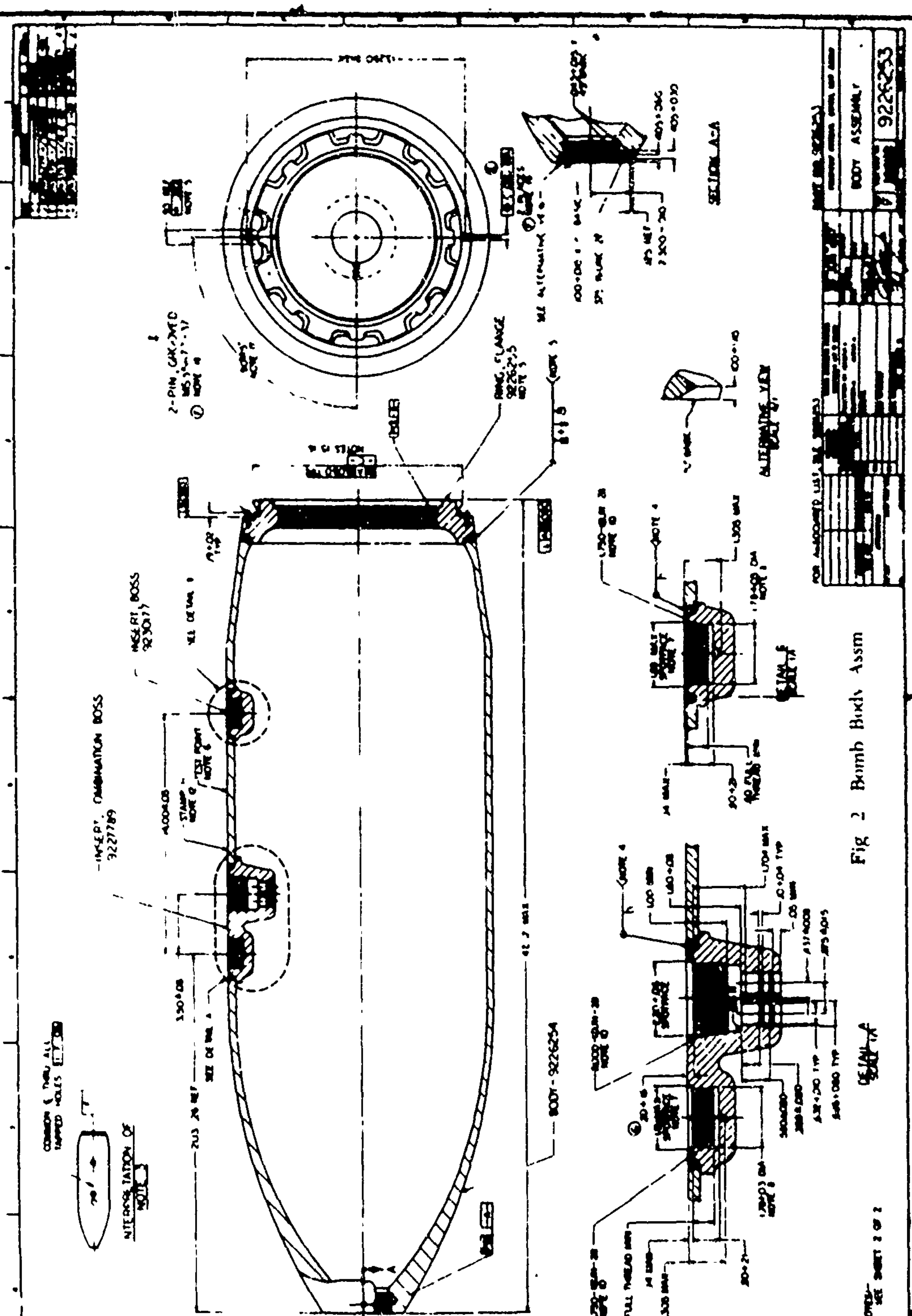


Fig. 2 Bomb Body Assm

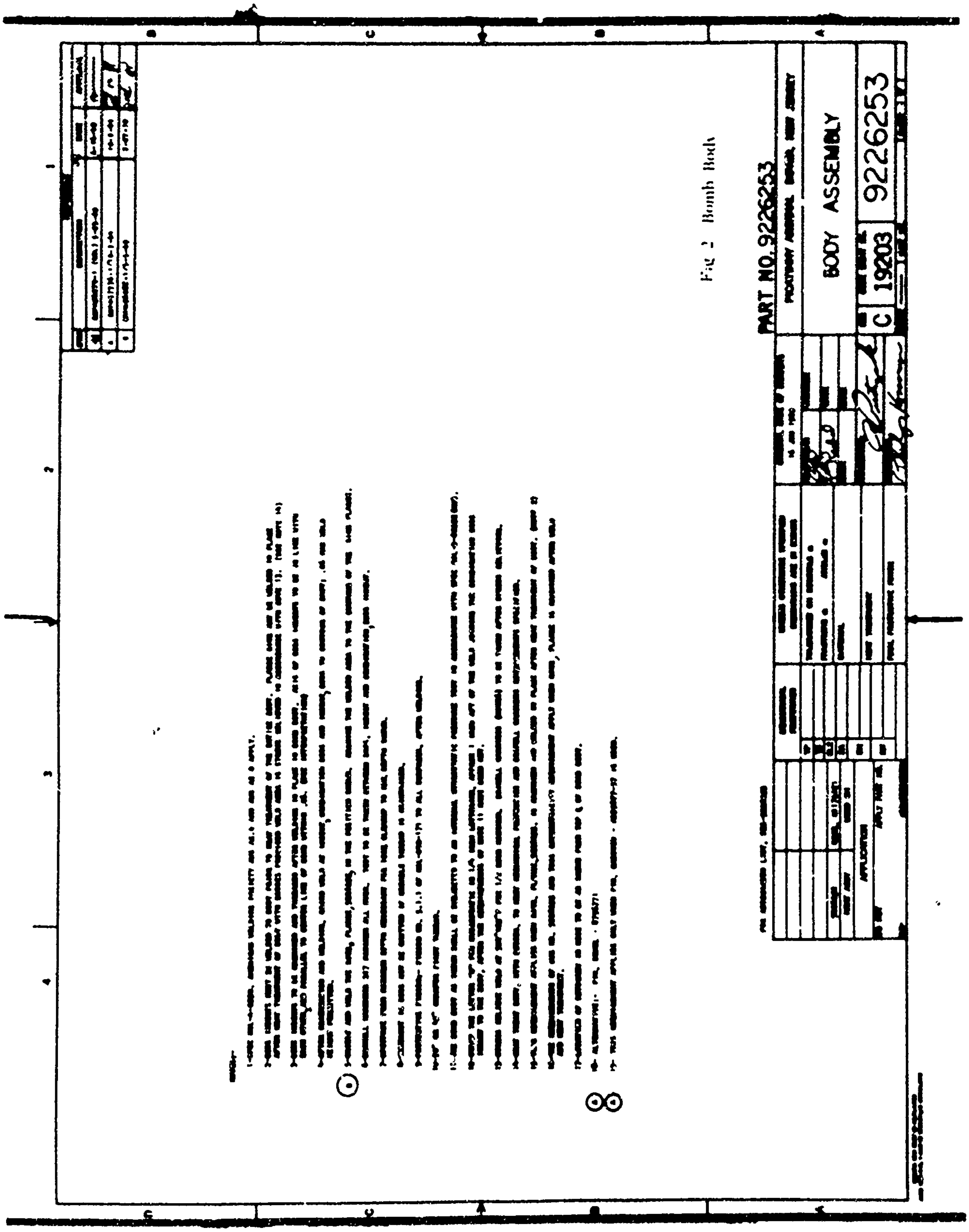


Fig 2 Bomb Body

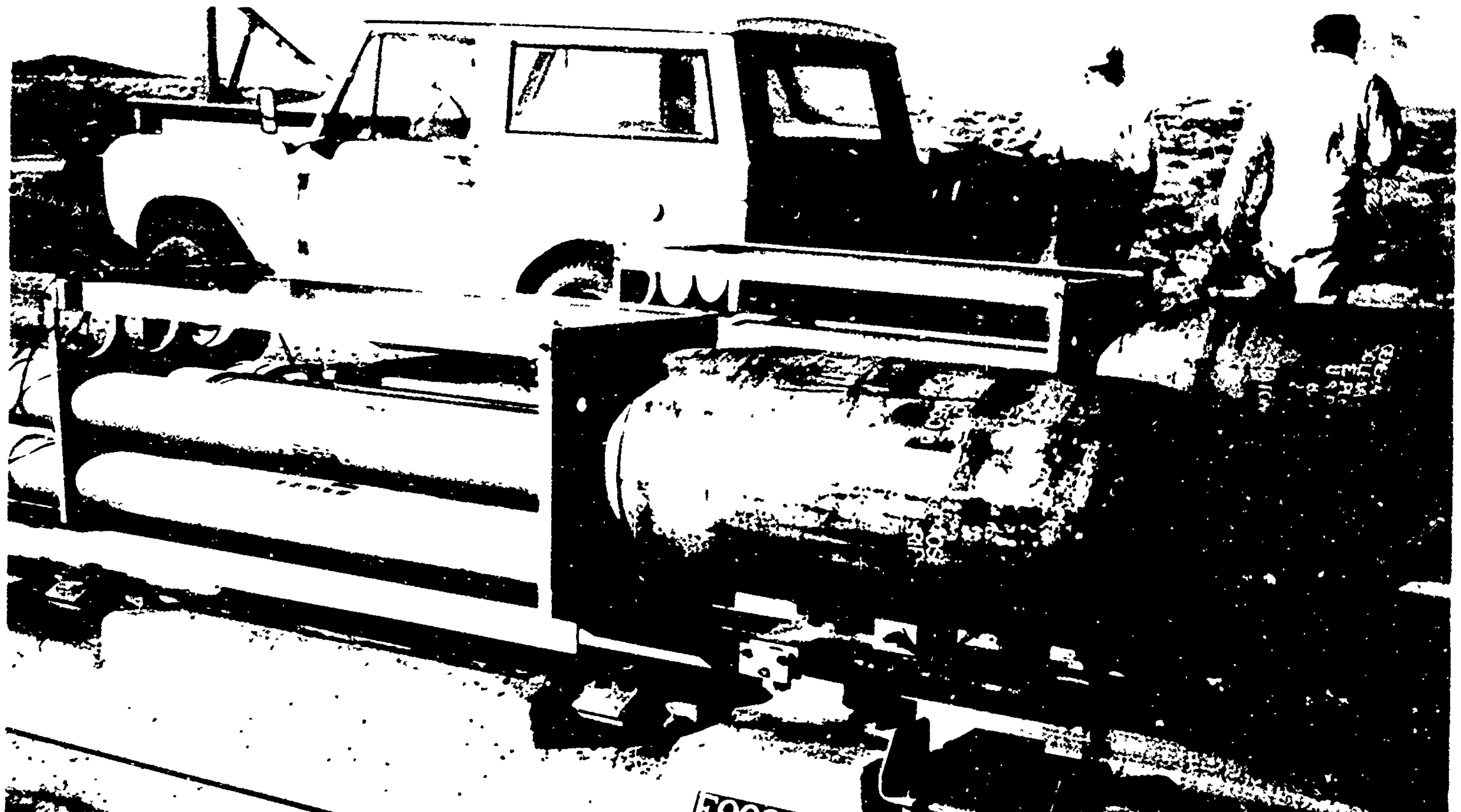


Figure 3 - Photograph showing bomb assemblies ready for Rocket Sled Impact Tests (RSIT)

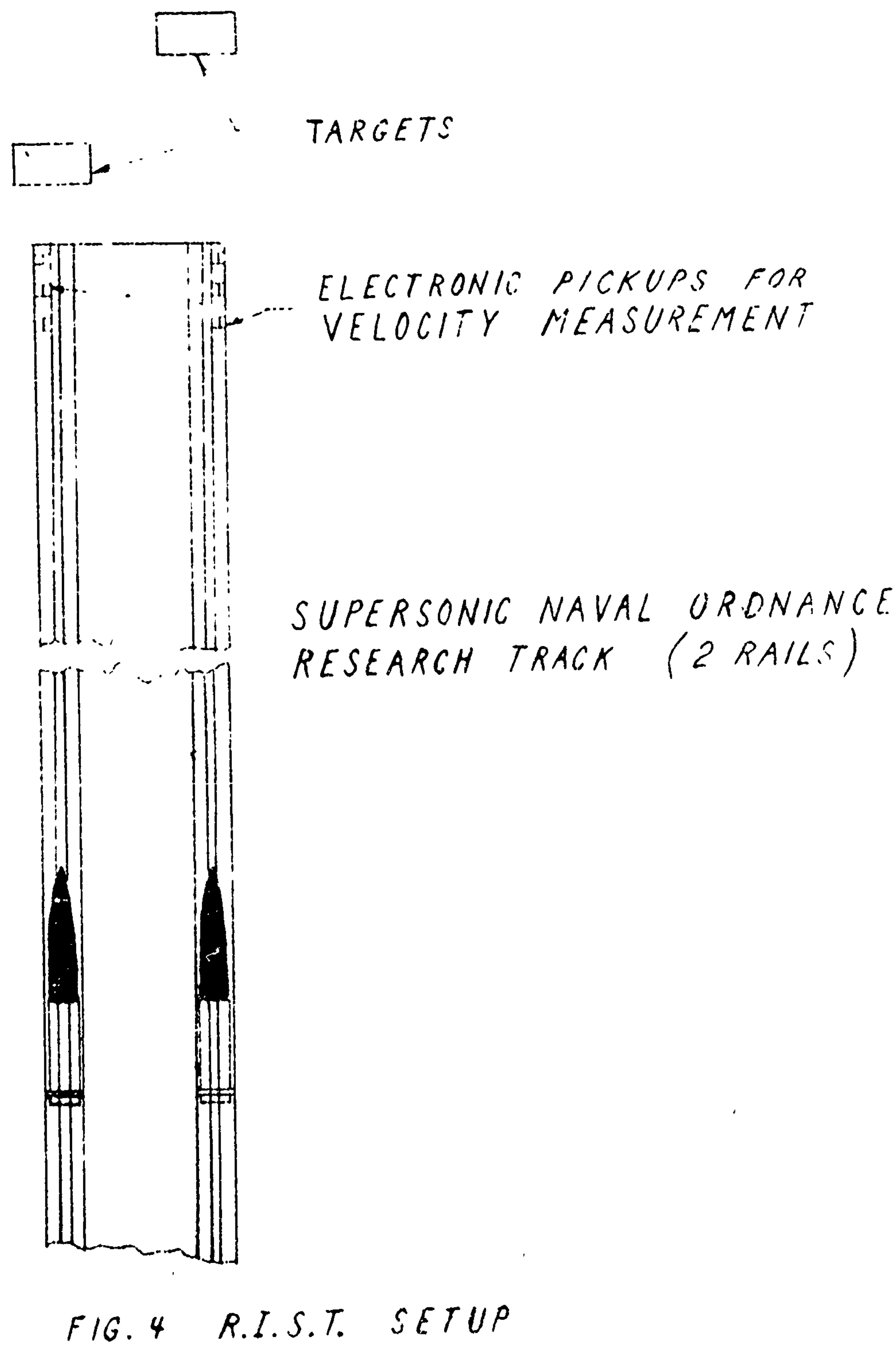


FIG. 4 R.I.S.T. SETUP

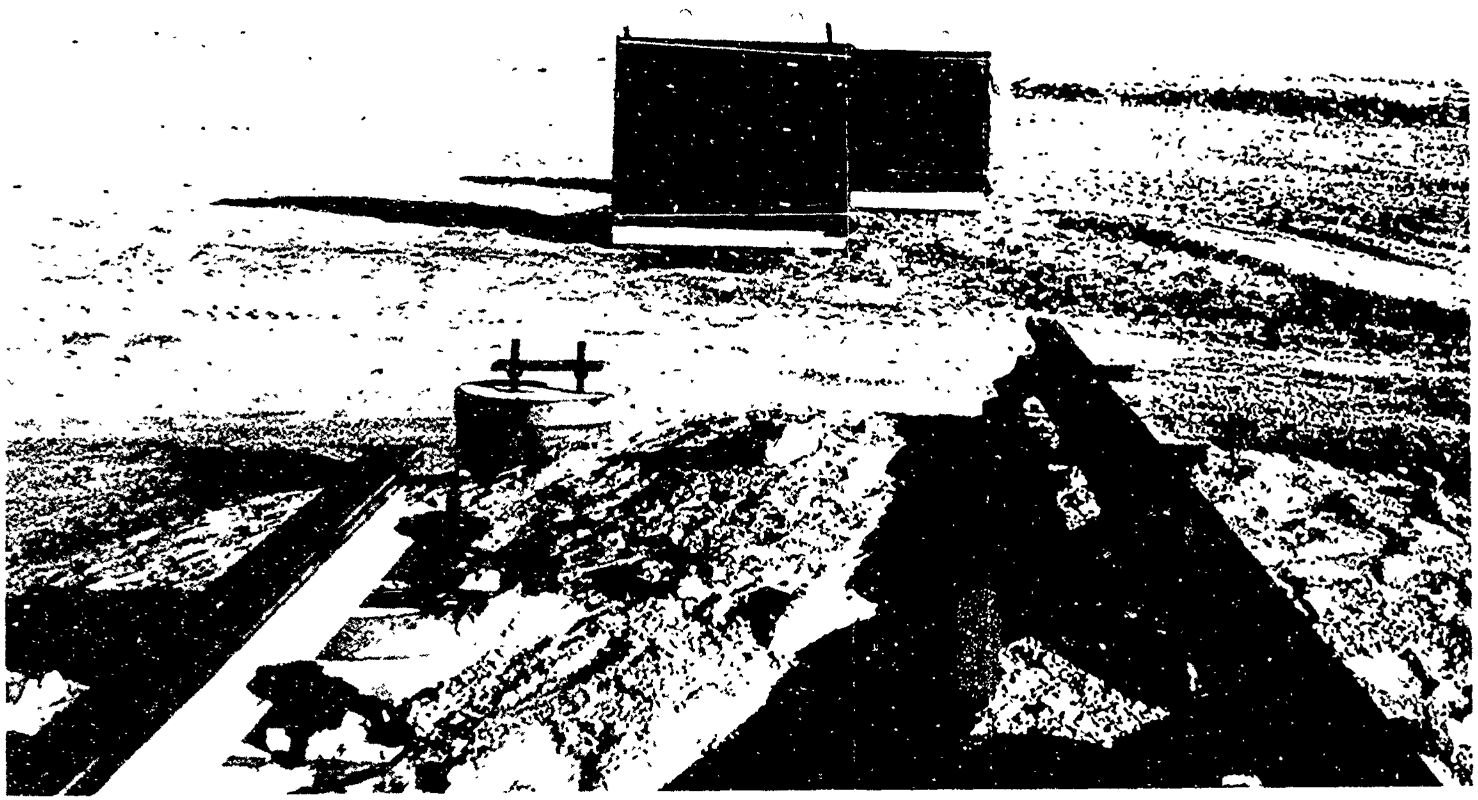


Figure 5 - Photograph showing two reinforced concrete targets and dual-rail test track

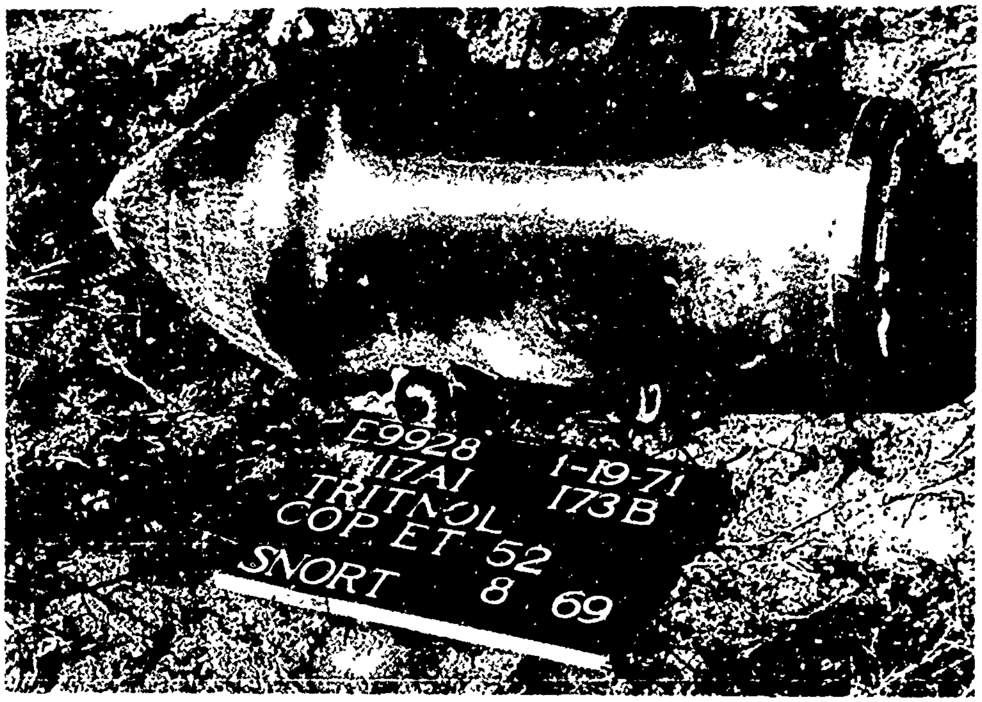


Figure 6 - Photograph of Bomb Body Assembly showing slight (bulging) damage after RSIT

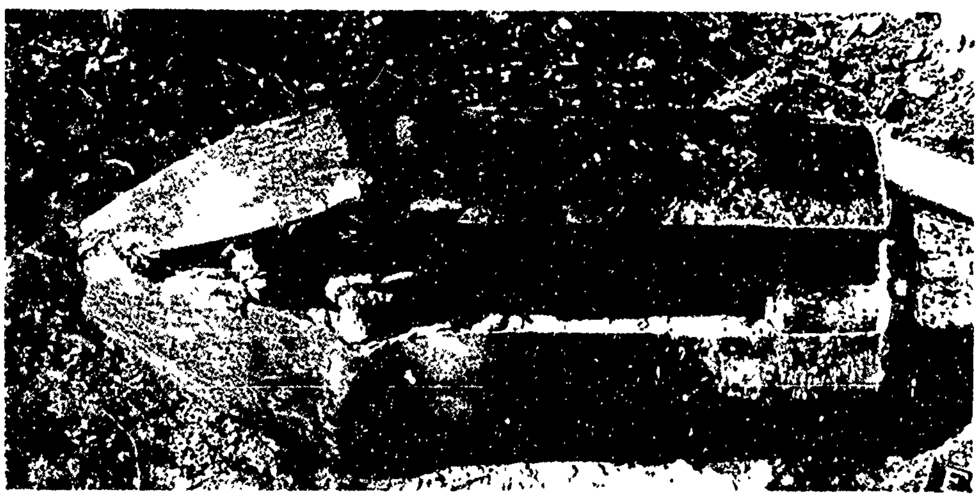


Figure 7 - Photograph showing bomb-body which split open and bulged during RSIT

Figure 8 - Photograph of bomb which detonated (fractured) upon target impact during RSIT

PROBLEM #4

DEVELOPMENT OF A RELIABLE NON-DESTRUCTIVE TESTING TECHNIQUE FOR DETERMINING YIELD STRENGTH OF ARTILLERY PROJECTILE BODIES ON A 100% BASIS

Edward E. Dougherty
Ammunition Development and Engineering Laboratories
Frankford Arsenal
Philadelphia, Pa.

Mechanical property requirements for artillery projectile bodies are usually established based on an analysis of stresses occurring during ballistic firing. These requirements permit an insignificant amount of plastic deformation to occur in the gun tube. Any elastic deformation that occurs is matched by expansion of the tube. In an effort to preclude overdesign, components with low properties are tested, usually at excess pressure, to determine whether requirements can be reduced. For all of the Army's production rounds, 105mm, 155mm, 175mm, 8 inch, etc., requirements have evolved over the years and represent properties below which problems begin to appear.

In most instances, the problems that arise are relatively minor and are related to measurable permanent deformation of the shell. This can produce inconsistent flight characteristics or excessive gun wear. However, on occasion, low mechanical properties can result in gross failure of the component and high order detonation. This in turn results in an intolerable loss in terms of both equipment and personnel.

Currently, most artillery projectile bodies are made by the hot forge and heat treatment method although some are made by cold extrusions or by hot cup cold finishing processes. Tests for mechanical properties are made after heat treatment, or for the cold finished bodies, after stress relief. Samples for testing are obtained either by random selection or as the result of a hardness survey. Where hardness is used as the criterion for selection, hardness is obtained of all shell in the lot, or of a representative sample of these shell, and the hardest and softest tested for compliance with tensile requirements. In some instances, a hardness range is established and components which fall outside this range are rejected. Since the hardness test is usually performed prior to finish machining, it is considered to be non-destructive in nature.

It has always been assumed that the yield strengths of all bodies lie between those of the hardest and softest. Further, the hardness distribution is assumed to reflect the distribution of tensile properties. In truth, these assumptions, while correct for the majority of compo-

nents, do not preclude entry of substandard items into the supply system. Most shell producers, along with the Army's engineering agencies, now agree that there is rarely a reliable correlation between surface hardness and mechanical properties displayed by subsurface material. However, it appears to be the best tool available although a strong case could probably be made for the superiority of random sampling.

The primary difficulty of the hardness test for this application is that the shell usually possesses some heat treating scale and exhibits some degree of decarburization. Thus a realistic reading is not obtained. On many occasions (18 of 69 for one series of 152mm XM409 projectile lots), the harder body displayed a lower yield strength than the softer one. Even a good reading, while it may be a good indication of tensile strength, may have no relationship whatsoever with yield strength. Experience with a 52100 steel projectile body has shown that at a hardness of Rockwell C31, the yield strength may range from 70,000 to 135,000 psi. These latter results are based on hardness readings taken on clean subsurface material.

It is obvious that the current system permits some sub-standard components to be accepted. Based on the acceptance level established, this cannot be avoided. The intention is that the factor of safety be sufficiently high to preclude the potentially troublesome shell. However, with the high level of performance expected of the new generation of shell, a high factor of safety is not always practical. As a result, it will become necessary to screen-out even marginally defective components. This is not possible with the current technique. An ideal mechanical testing technique for these shell would permit automatic non-destructive determination of yield strength, tensile strength, and ductility of the complete shell configuration on a 100% basis. However, determination of yield strength alone on one or two areas of the shell would be considered a fantastic achievement. Parts not meeting requirements would be set aside for reheat treatment.

As far as can be determined, no work has been done in this area. Work has been performed attempting to relate hardness to ultrasonic characteristics and relating residual stresses to x-ray diffraction patterns. These processes have even been automated through use of high speed image analyzing computers. Perhaps these might be good starting points. Eddy current and conductivity tests are also capable of characterizing the metal structure to some degree. However, no correlation between any of these tests and yield strength has ever been reported.

Equipment used for this type test should be capable of evaluating three components per minute. The components will, in most cases, be carbon or alloy steel and range from four to eight inches in diameter and from twelve to 36 inches in length. Most projectile bodies possess an ogival forward area, a straight sidewall, and a tapered boattail area. It is hoped that eventually equipment will be developed suitable for incorporation into production lines.

Commanding Officer, Frankford Arsenal
Philadelphia, PA 19137, ATTN: E. E. Dougherty

SUMMARY REPORT OF PROBLEM NOS. 3 & 4

DEVELOPMENT OF A RELIABLE NONDESTRUCTIVE TESTING TECHNIQUE FOR DETERMINING YIELD STRENGTH OF ARTILLERY PROJECTILE BODIES ON A 100% BASIS

J. B. Small
Problem Coordinator

1. Problems Numbers 3 and 4 were handled in combination because of the similarity of conditions:

a. They both use hardness testing on a sampling basis for determining compliance of the end items with required material mechanical properties.

b. They have both found instances where the use and compliance hardness test has still resulted in failure to meet desired performance characteristics.

c. They both seek a nondestructive method suitable for production that will check the adequacy of the end item to meet performance characteristics as far as the material is concerned.

2. The problem discussion, both from the floor and at the problem-solving session, was varied and extensive, so that individual credit is impossible. The discussion generally was divided into answers of three categories and were equally applicable to both problems:

a. Those solutions involving changes in process and design to guarantee proper grain flow, martensitic structure in end item, and absence of voids in explosive casts.

b. Those solutions which dealt with more use of standard NDT methods such as:

(1) X-ray for gross flaws in material and explosive cast.

(2) Eddy current and ultrasonic testing for material flaws.

(3) Improved hardness testing for better picture of structure, including check for localized hard spots.

(4) Internal hydraulic testing to a nondestructive limit.

c. Those solutions which involved the generation of data including checking failure modes, target variables, manufacturing variables, and material variables.

3. Based on an analysis of the discussions, the consensus on the solutions is as follows:

a. While NDT methods can be calibrated to give comparative indications of mechanical properties such as yield and tensile strength, they do not lend themselves to quantitive uses on a production basis.

b. The current NDT techniques can be applied to both problems to improve the current situation, i.e., use of selective hardness testing over larger areas. Use of eddy current or ultrasonics to monitor gross material or process defects.

c. The problems point up a need for basic research in NDT techniques so that adequate measures of mechanical properties of metals can be made on a production line.

4. Some mention should be made of the fact that Problem #4 had the elements for a separate problem; that is, that some of the artillery shell discussed are made of special steels, designed to be brittle and to optimize fragmentation on impact. This condition automatically reduces the leeway in ductility afforded to the more historical uses of shell and requires more precise and reliable measurements of the mechanical properties of the end item. The catastrophic results of brittle failure of the shell in the weapon need not be elaborated on. Therefore, it is suggested that as soon as sufficient development data on these new type shell become available, they could be considered as a separate topic for NDT techniques.

J. B. Small
Picatinny Arsenal
Dover, NJ

PROBLEM #5
By
Mark H. Weinberg
Picatinny Arsenal

INSPECTION OF ELECTRON BEAM WELD IN BODY ASSEMBLY FOR WARHEAD, GUIDED MISSILE, HE, XM250 (CHAPPARAL)

Mr. Chairman, Ladies and Gentlemen:

I will begin the presentation by describing the item under consideration, its modes of use and the reasons we need a reliable nondestructive test. Following that, I shall identify the problem area in uetail, describe the work we have done to date and our thoughts for the future; then I shall look to this august and able assemblage for pertinent proposed procedures.

The end item, as you have seen by your copy of the abstract, is the Chapparal Guided Missile. *(FIGURE 1)* This is a ground to air weapon about 9 1/2 feet long. Here you see one *(FIGURE 2)* resting on its assembly stand. The major sections are: the rocket motor and flight stabilizing surfaces, the warhead (this is the section for which Picatinny is responsible), the target detecting device together with the safing and arming device and the guidance section with control fins.

(FIGURE 3)
The Chapparal is [illegible]gned to be transported in and fired from this vehicle. Under battle conditions four missiles will be on the launch rails (two on either side); additional missiles are stored below.

(FIGURE 4)
The "fire" configuration is shown here. The turret is elevated and the missiles can be given their launch attitude.

(FIGURE 5)

With this photo we begin to see our problem developing. Note that the missile is supported on the launch rail at mid-point. The entire forward end is cantilevered. Thus as the vehicle travels the transportation shocks and vibrations cause relatively high bending stresses on the structural members. You will recall that the warhead section lies in the first third of the missile length, and so is not supported by the launch rail.

(FIGURE 6)

Here we see a cross-section of the warhead section. The outer shell, approximately 5 inches in diameter, is currently being machined from a forging of 6061 aluminum and is heat treated to the T-6 condition. The aft end of this casing is ultimately assembled to the rocket motor. The forward end, which assembles to the target detecting device and safe-arming device, is currently being machined from bar stock, also 6061-T6. Within the outer shell is a relatively heavy warhead assembly suspended between supporting members of the shell. These internal components provide no significant structural strength to the warhead. This function is performed entirely by the outer skin. The shell and warhead are joined at the forward end by a shrink fit (with 0.005" to 0.008" interference) and by the electron beam weld. The aft end of the warhead assembly screws into the aft end of the outer shell during the shrink fitting operation. During that operation the outer shell, heated to 350°F, is spun down over the inner assembly (which is packed with

dry ice) until it seats on the shoulder shown in this enlarged view of the forward end. After welding, the weld area and the forward end are finish machined to the configuration shown in the upper drawing.

The primary structural member supporting the forward end of the missile is the electron beam weld. This weld, thus, is subjected to the transportation shock and vibration stresses noted earlier. It also must withstand the stresses imposed by very high rates of turn as the missile tracks the target. If the weld fails, it is likly that the missile will break up. Thus the cost of the missile plus the logistic costs associated with bringing it to the point of firing will be lost; more importantly, the aircraft at which it was aimed will be able to continue on its mission, presumably hostile to our forces.

We are not without some controls on the quality of the weld. The warhead specification, MIL-W-50849, requires that a metallographic examination be conducted on a representative sample of the weld at the beginning and end of each shift. The samples used are required to be geometrically similar to the item in the weld area. The drawing showing the weld carries a note as follows: "Highly stressed weld-add sufficient filler material to assure no micro fissures in weld zone to .090 deep when examining section 300 X per MIL-W-46132." This latter specification covers Electron Beam Fusion Welding, and shows cross sectioning through the weld sample.

Let me give you a little more information. The finish on the surfaces which are shrink-fitted together is required to be no rougher than 125 micro inches RMS. Those surfaces must be free of contaminants at assembly, and have been acetone-wiped in parts made to date. The weld filler material is Aluminum Association alloy number 4047, containing 12% silicon. This is applied in strip form, 0.006" thick, wrapped tightly around the cylinder and clamped in place before the welding. The weld is performed in medium vacuum, 10^{-4} microns of mercury pressure.

While the sample sectioning for weld quality, coupled with process controls, will give a degree of product assurance, the serious nature of a failure impels us to seek a NDT which can be reasonably applied 100%.

It is my thought that the drawing requirement for the microscopic examination to reveal no cracks at 300 power cannot realistically be duplicated by any nondestructive test. We do not anticipate eliminating that requirement. What we do seek, though, is a test which will give us a grosser indication of the weld quality, such as indicating a good bond with penetration thru the outer shell and fusion at least to the minimum required width.

(FIGURE 7)

This is a photomicrograph, taken at 50X, of an early weld. No filler was used. This section was taken after the part had been stressed. Since the outer cylinder is 0.070" thick and the crack-free zone is required to be

0.090" deep, no cracks should be found within the 0.020" shown. We do, in fact, see such cracks in this photograph. Since this weld was made, changes were made in the process, improving the quality significantly.

Well, that's the problem. What have we done to develop a NDT?

1. We have tried radiography. Some radiographs were taken of welds made in assemblies which inadvertently contained an oil film on the interface. One can easily see voids all along the weld, in the form of dispersed bubbles probably caused by vaporizing oil. I have one of these films with me for your viewing. However, we anticipate no success using radiography to determine width and depth of weld or to detect cracks.

2. We made a brief effort with holographic interferometry. Insufficient work was done to come to any conclusions. We broke off further efforts because we consider this method probably not sufficiently sensitive to small defects and also not capable to measure a weld width.

3. Ultrasonics. We have placed the greatest emphasis on this method. Mr. Ed Bauer of our office has done the development work, and we have obtained some degree of success.

(FIGURE 8)

We designed a "standard" as shown here. The dimensions of the weld area duplicate those of the warhead. One end

ring had small blind holes and one shallow slot cut inward from the joint surface along the weld line before being shrink fitted to the cylinder. The other was left unblemished until after welding. All components were ultrasonically inspected with both longitudinal and shear wave before assembly, after assembly and after welding. The material was determined to be very clean ultrasonically.

(FIGURE 9)

Our initial efforts in ultrasonic inspection were directed to use of the delta configuration as shown in the upper illustration. However, it soon became evident that the lap configuration of the assembly and the small size of the weld were giving us an extremely noisy background, thru which we could expect to see nothing of the weld quality. We then switched to a small diameter, short focus 10MHz transducer, with a soft foam rubber aperture stop fixed in front as shown in the lower sketch. This gave us the means to project a narrow beam thru the weld to the inner surface, and to get a good back reflection. Using one of the assemblies with gas bubbles, we could see the back reflection appear and disappear as the item was rotated. If we directed the beam at an unwelded area, the back reflection was lost in the water-metal interface signal. We have, therefore, demonstrated a capability to "see" voids and to determine if a weld does penetrate. Perhaps some refinement of this method will enable us to determine the width of the weld. We doubt it will be able to detect fine, tight cracks. However, this is the most promising approach yet.

4. We have considered acoustic emission. This would require establishing the stress level to be applied and the manner in which to apply the stress. Complexity of the assembly may make this a very difficult method to use.

5. We also considered acoustic resonance. Again the complexity of the item leads us to believe that the probability of success in applying this test method is low.

6. A mechanical stress test may hold some possibility. Since the two major components are joined at both ends, aft by a threaded joint and forward by the weld, determination of a satisfactory nondestructive test level and the means to differentiate between acceptable and rejectable welds could present formidable problems.

7. Eddy current - If someone has successful experience applying this to a similar problem, we would like to get some concrete, specific suggestions.

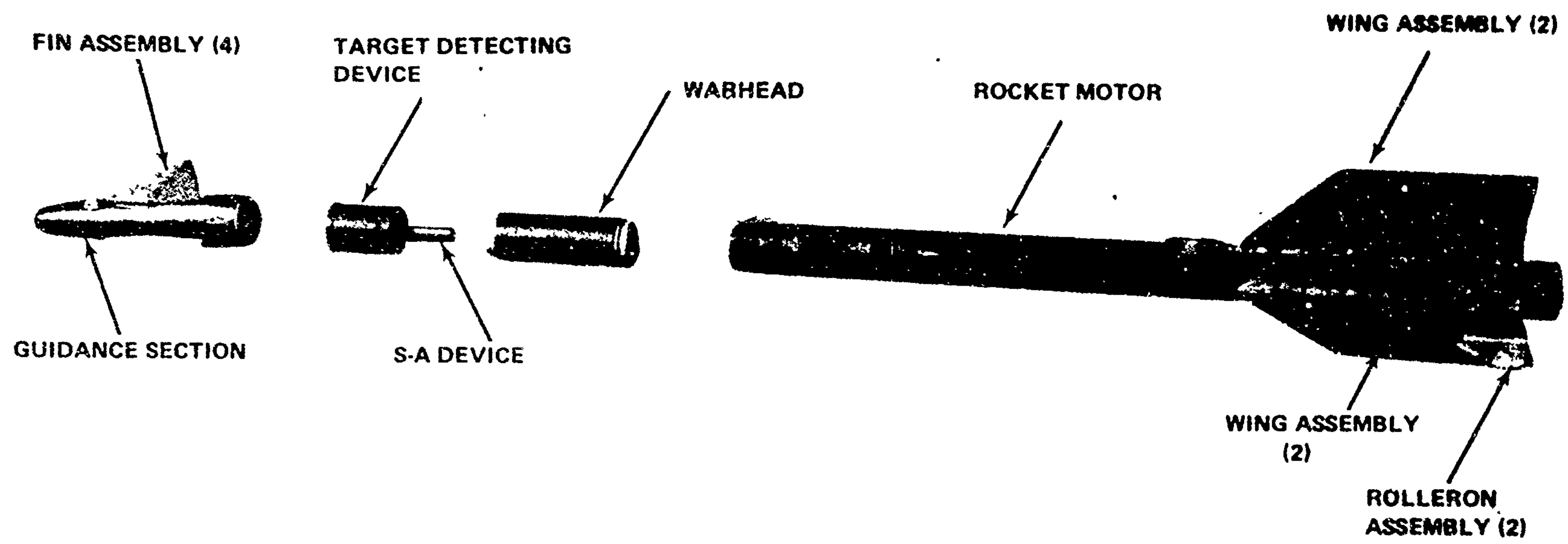
8. Infrared we consider probably not sensitive enough.

Ladies and Gentlemen, you now know of our problem, our efforts and our thoughts. May we have the benefit of your experience and ideas? Thank you......

Picatinny Arsenal
SMUPA-QA-A-R, Bldg. 94
Dover, NJ 07801
ATTN: Mark H. Weinberg

FIGURE 6-15 (U). MISSILE ASSEMBLY STAND (U)

FIGURE 1



WEIGHT	84.7 KILOGRAMS (187 LB)
LENGTH	2.9 METERS (114.5 IN.)
DIAMETER	0.13 METERS (5.0 IN.)
WING SPAN	0.63 METERS (24.8 IN.)
FIN SPAN	0.41 METERS (16.4 IN.)

FIGURE 2-1 (U). CHAPARRAL MISSILE XMIM-72A (U)

FIGURE 2

FIGURE 4-26 (U). MISSILE STOWAGE CASE REMOVAL FROM LAUNCHER STOWAGE BIN (U)
FIGURE 3

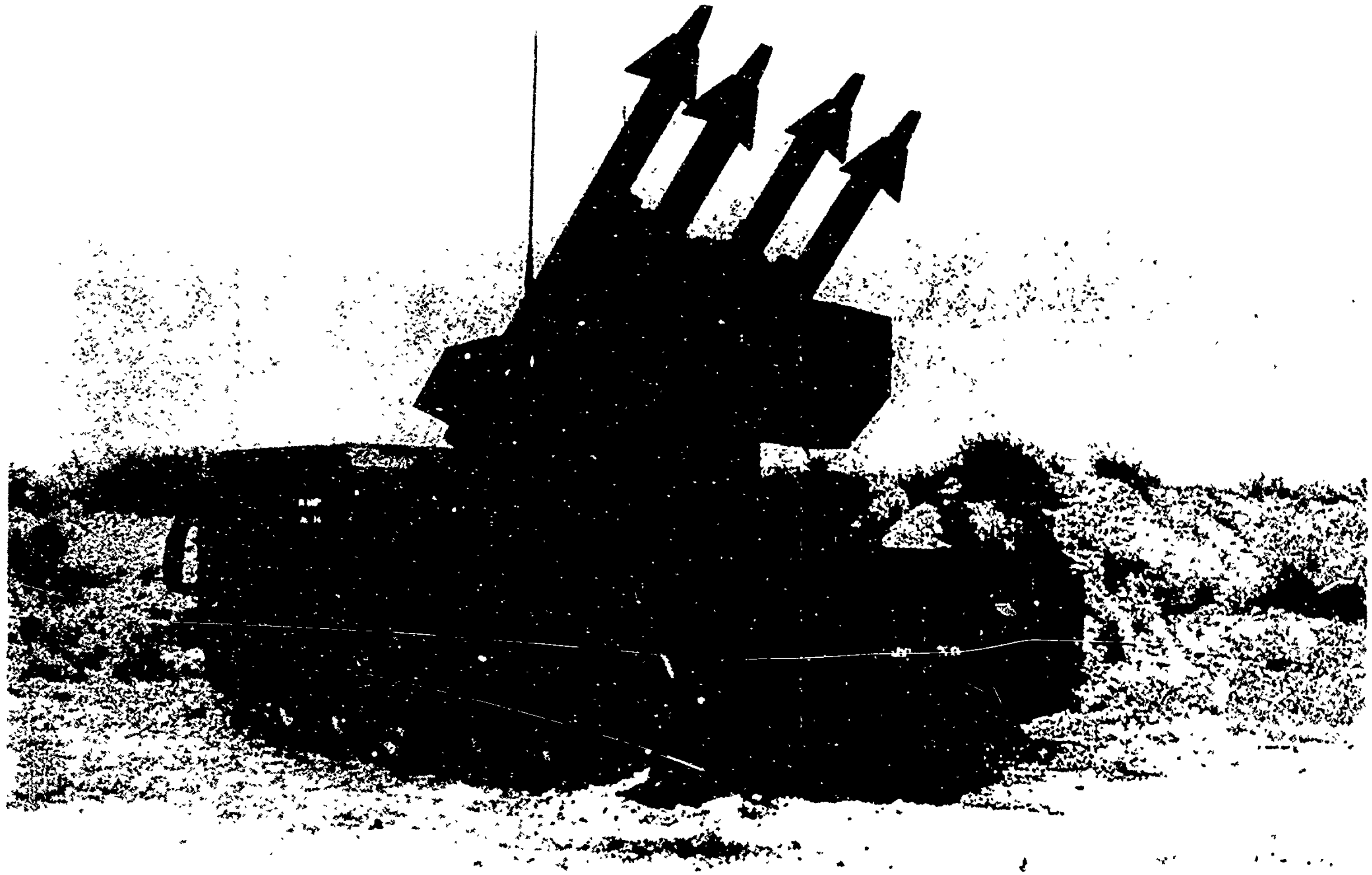


FIGURE 5-2 (U). CHAPARRAL FIRE UNIT CONFIGURATION (U)
FIGURE 4

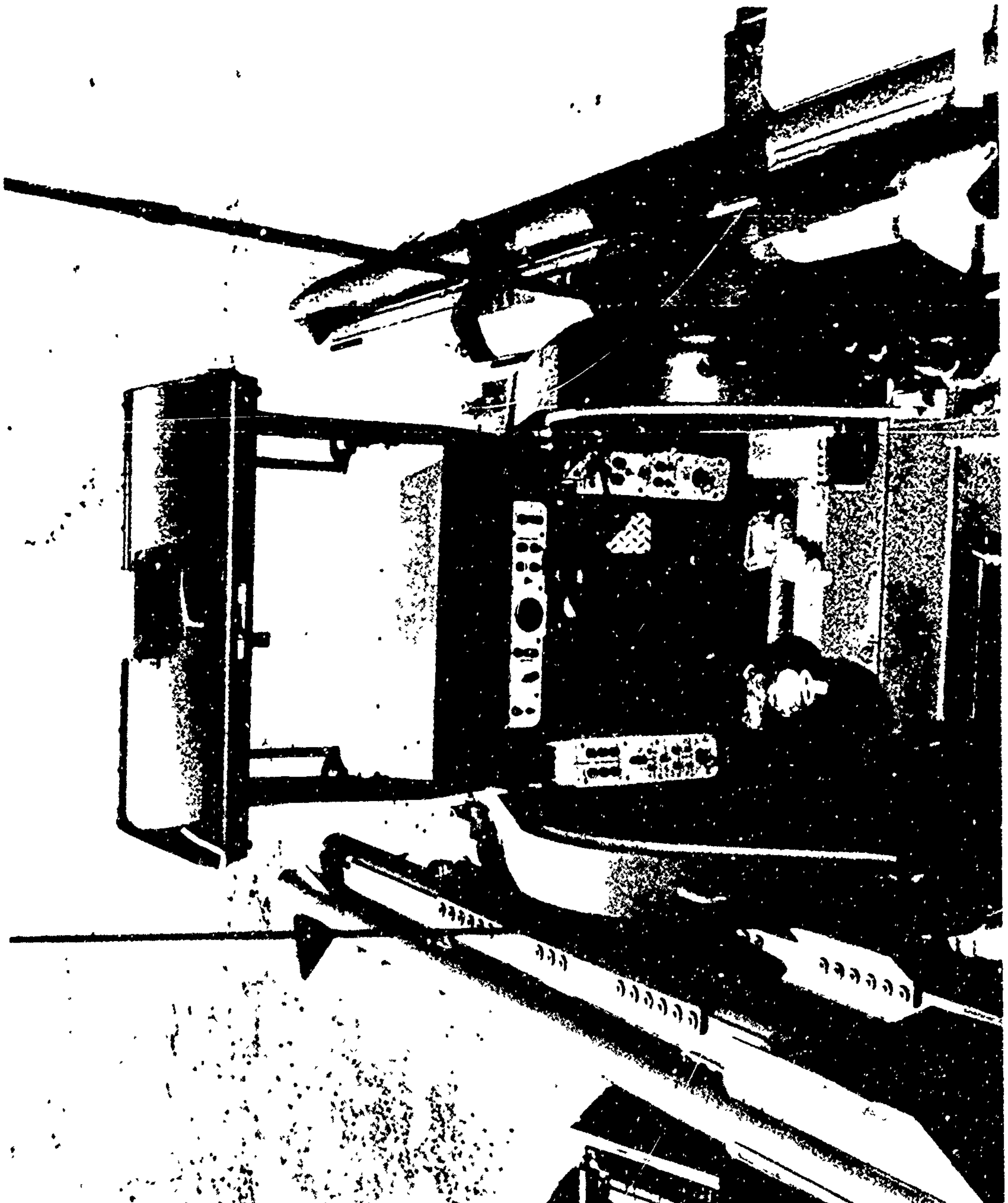


FIGURE 4-21 (U). LAUNCHER TURRET CANOPY (U)
FIGURE 5

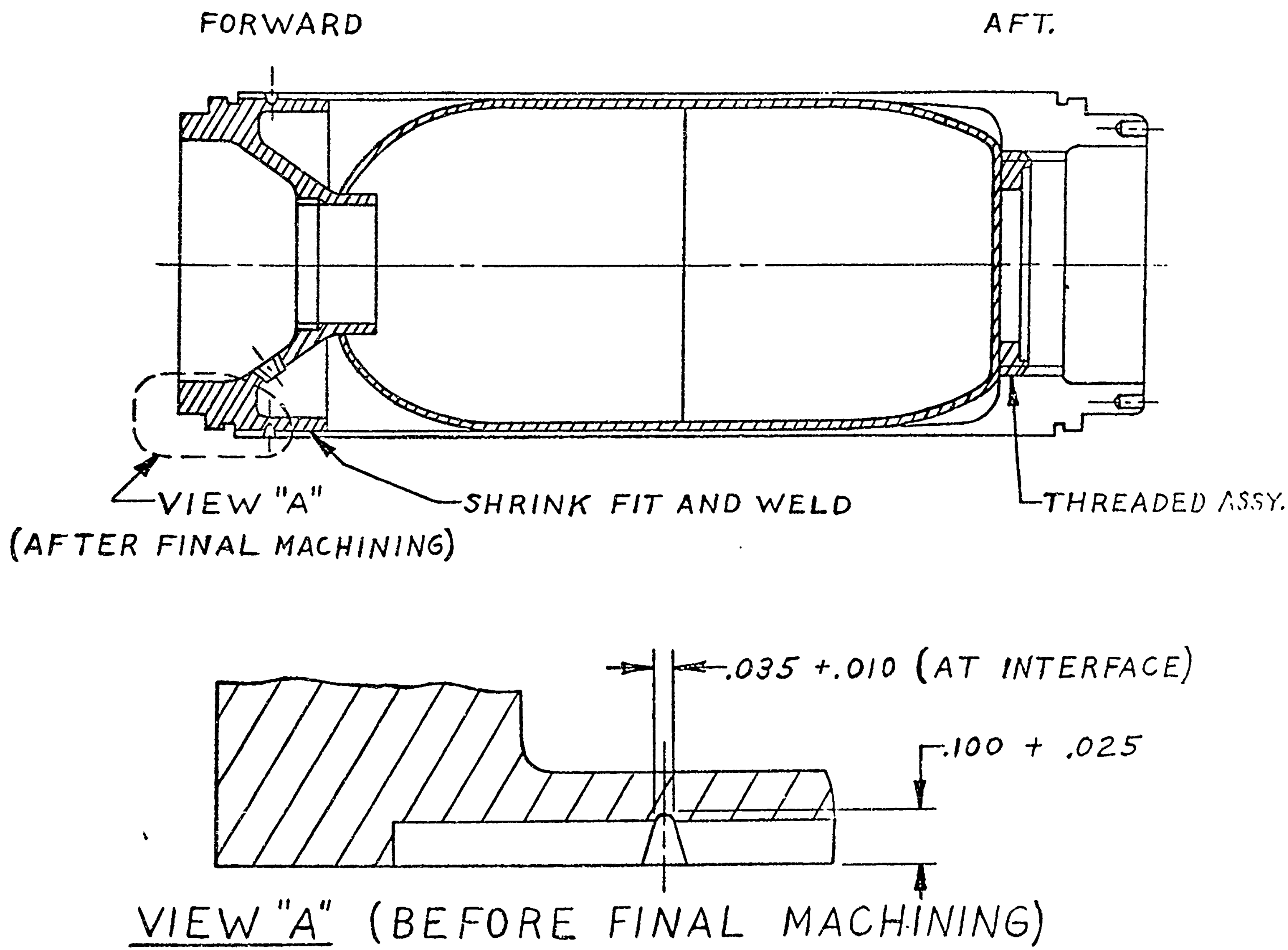
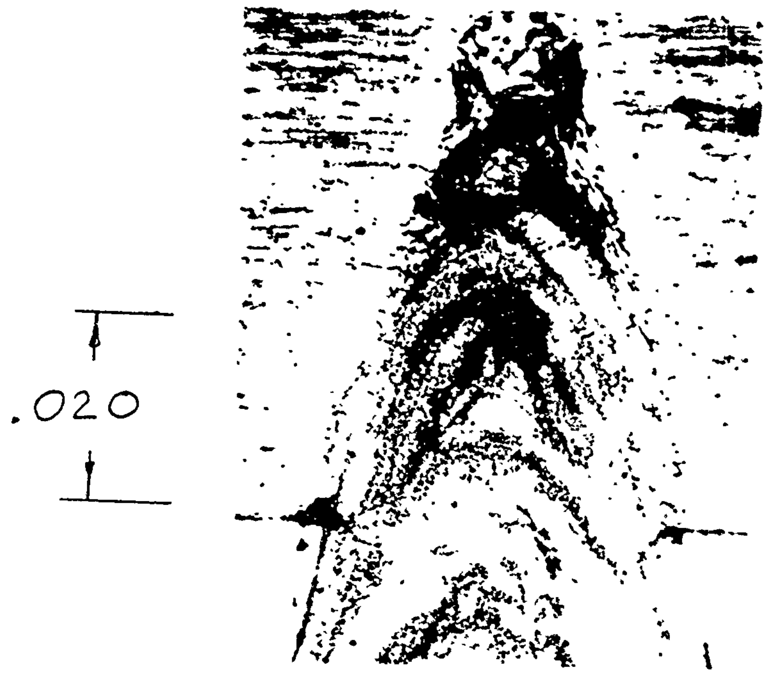
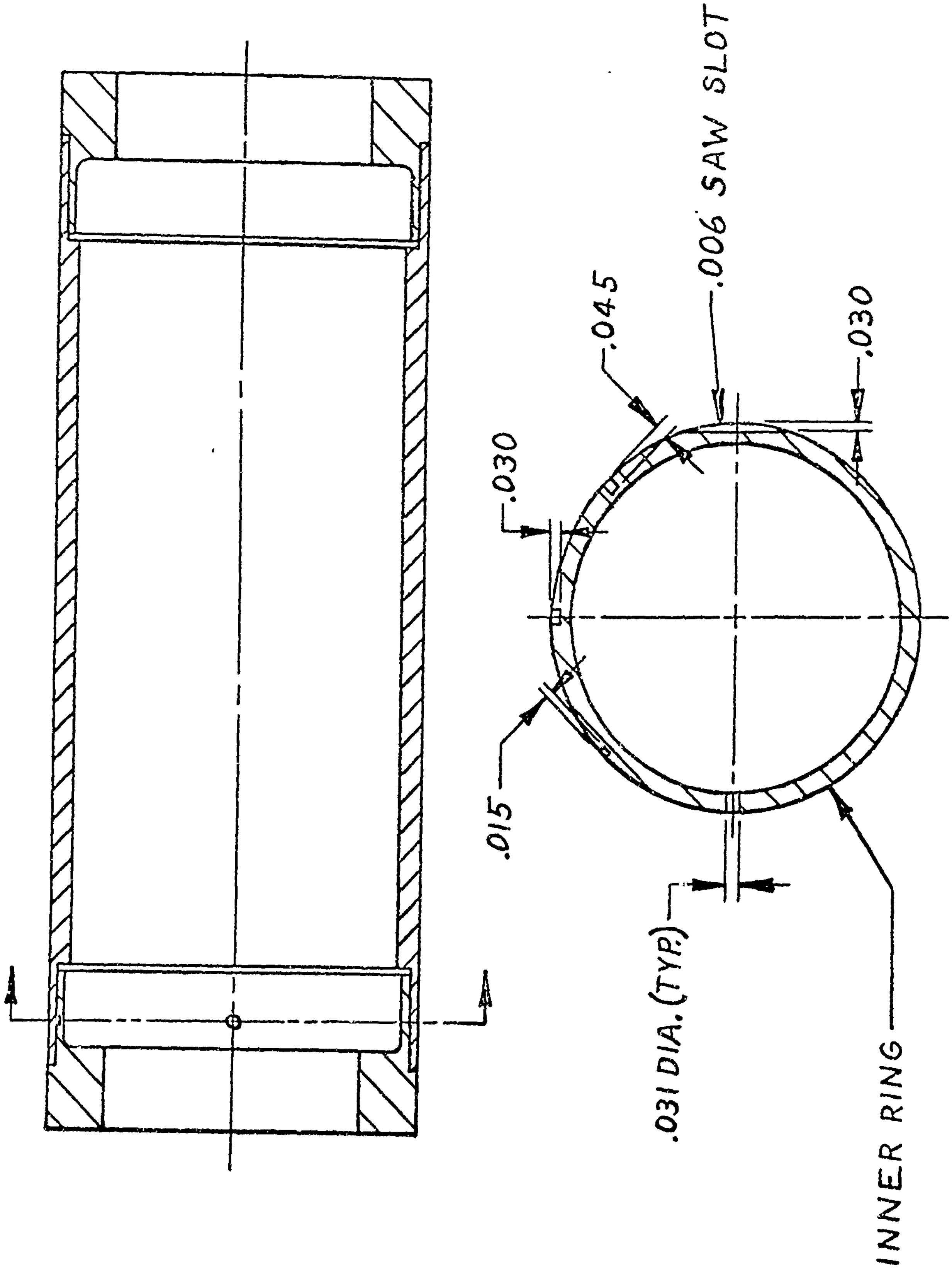

FORWARD
AFT.
VIEW "A"
(AFTER FINAL MACHINING)
SHRINK FIT AND WELD
THREADED ASSY.
.035 +.010 (AT INTERFACE)
.100 + .025
VIEW "A" (BEFORE FINAL MACHINING)

FIGURE 6



Weld Bead

Figure 7. Specimen EBI-13-14. Kellers Etch. 50X



ULTRASONIC "STANDARD"
FIGURE 8

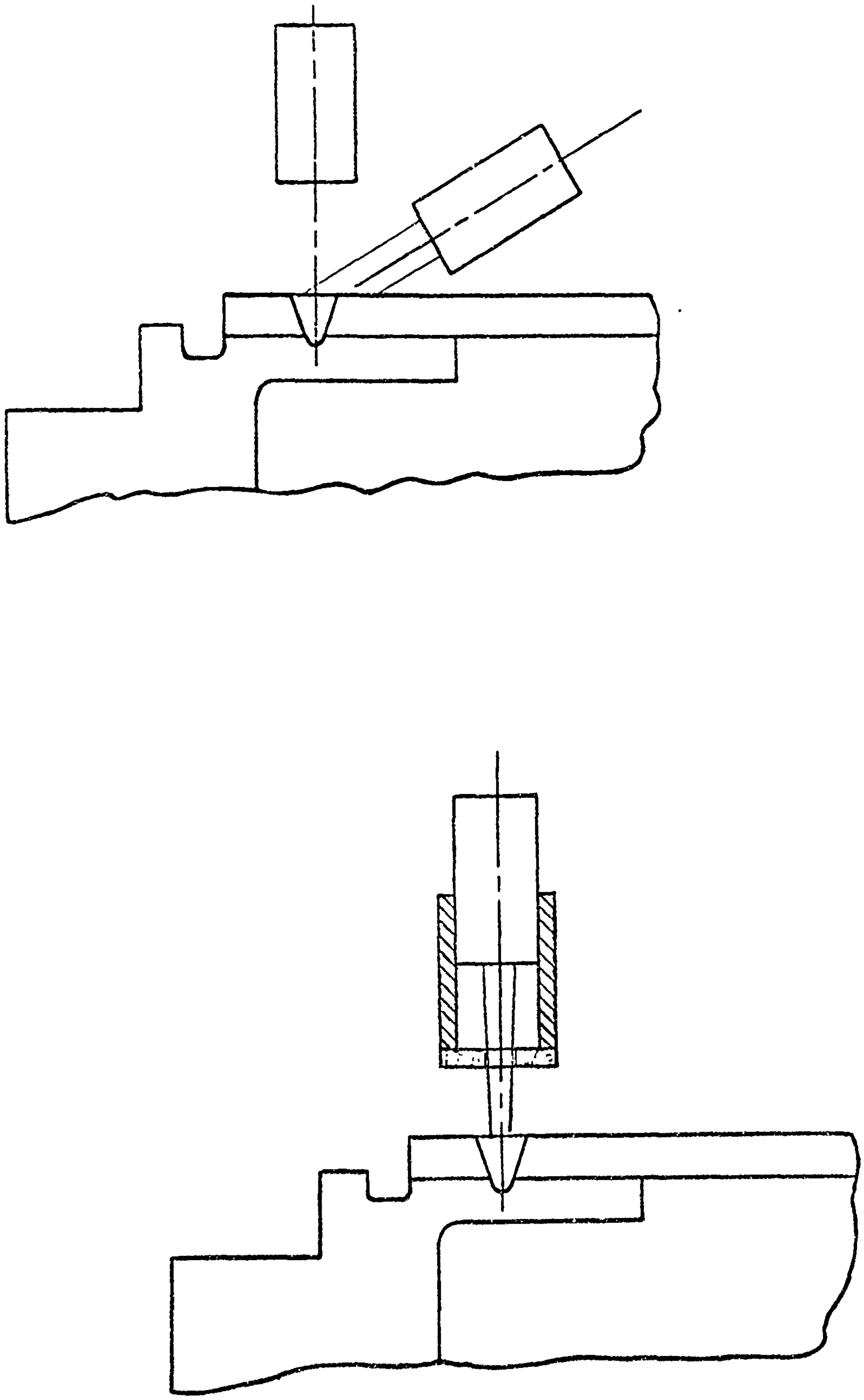


FIGURE 9

SUMMARY REPORT OF PROBLEM NO. 5

INSPECTION OF ELECTRON BEAM WELD IN BODY ASSEMBLY FOR WARHEAD, GUIDED MISSILE, HE, XM250 (CHAPPARAL)

David Stein
Problem Coordinator

1. Stephen Hart, NRL Washington, D. C. - Recommended that, in the use of an ultrasonic approach, one would need both high resolution transducers and pulse generators producing very short pulses; these should provide better delineation of weld width and detection of cracks. He suggested some sources for obtaining the transducers commercially.

2. John Lien, DCASR, Los Angeles - Suggested the use of a "Pitch and Catch" contact ultrasonic method, using a 5-megahertz transducer.

3. Albert Rogel, McClellan AFB, California - Suggested an ultrasonic-focused transducer used in C-Scan mode.

4. Clen Henderson, Norfolk Naval Shipyard - Suggested an ultrasonic thickness measuring device, the Sonic Digital Thickness Gage, manufactured by Sonic Instruments, and furnished a report evaluating this equipment's capabilities. The characteristics of excellent precision and high resolution are thought to be useful for contributing to the measurements of the weld geometry.

5. James Brink, NSRDC, Washington, D. C. - Suggested using replaceable type delay line ultrasonic transducers. He recommended not using shear wave in the axial direction because of his experience on a similar application, which resulted in the generation of excessive "noise" because of entrapment of the sound energy.

6. LT Dee Graber, Bergstrom AFB, Texas - Suggested applying a noise-free cyclic heating and cooling to induce cyclic straining, and to sense any ultrasonic acoustic emission with an ultrasonic microphone. However, there may be a possibility that the noise generated at the shrink-fit surfaces will mask the emission of concern.

7. Mike Stellabotte, NADC, Warminster, PA - Suggested a phase-sensitive eddy current device: Phasemaster, manufactured by Laser Systems and Electronics Company, Tullahoma, Tennessee.

8. Domenic Molella, Picatinny Arsenal, Dover, NJ - Provided a contact to advise on the use of Holographic Interferometry. In the presentation, it was mentioned that this might not be able to provide the necessary detectability of cracks.

9. Elvin Fritz, NARF Alameda - Made some helpful suggestions concerning the cleaning process prior to welding.

10. Ken Fizer, NARF NORVA - Recommended using a single-pass weld because multiple-pass welds tended to produce cracks. Both Messrs. Fritz and Fizer questioned the use of 4047 aluminum instead of 6061 as filler material. The suggestions of both will be relayed to the design personnel at Picatinny Arsenal.

11. Joseph Cipriani, NADC, Warminster, PA - Will be contacted to arrange for use of his equipment described in his presentation on bearing inspection.

David Stein
SMUPA-QA-TT
Picatinny Arsenal
Dover, NJ 07801

PROBLEM #6

DEVELOPMENT OF A TECHNIQUE TO DETERMINE SOUNDNESS OF FRICTION WELDS IN HIGH EXPLOSIVE MUNITIONS

Edward E. Dougherty
Ammunition Development and Engineering Laboratories
Frankford Arsenal
Philadelphia, Pa.

Recently, there has been much interest in producing ammunition items through the use of friction welding. Friction welding can be applied to most multipiece ammunition components currently assembled by the manufacturer. In addition, several items now made in one piece will be more economical to produce if a multipiece design suitable for friction welding is adopted. Since welded joints, unlike brazed joints, can be heat treated after joining is accomplished, heat affected areas which are normally zones of weakness can be eliminated.

The current method for joining tubular ammunition components such as two portions of a shell body or a burster container is by threading or brazing. Threads require extensive preparation and possess areas of inherent weakness at their roots. In addition, it is usually necessary to incorporate thread sealants which produce little more than a mechanical bond and very seldom result in an air tight seal. Brazing likewise requires extensive surface preparation. Surfaces to be brazed must be extremely clean to assure wetting by the brazing material. In addition, extremely close tolerances are required to assure compliance with strength requirements. Production experience has shown that acceptable joints are produced only after extensive critical discussions with the contractors involved.

Friction welding can also be used as a tool to reduce press capacity requirements for many new shell plants now being considered under the modernization program. This can be realized through utilization of friction welded process pieces in lieu of large forgings or extrusions which require high tonnages to produce. These process pieces would then be drawn or extruded to produce the final shape. Items so produced would hopefully be as strong as items produced from one-piece forgings. Potential savings to be realized from this approach amount to several million dollars yearly.

In the development and manufacture of certain types of ammunition, there is increased interest in joining of dissimilar metal combinations. Friction welding has proven to be quite versatile in this area. For example, tungsten and uranium base materials often function as penetrators or range extenders because of their high density. Howevever, the component cannot be made entirely of these materials because of fabrication problems or other requirements. As a result, a joint must be effected with steel, aluminum and other materials.

The primary objection to friction welding is the inability to non-destructively determine joint soundness. This is particularly important in shells produced for high explosive loading. Currently, the friction welding industry points to the repeatability of the process as assurance of reliability. They can show that the same amount of energy in the form of torque and thrust is applied to each weldment. The uniformity of flash produced along with the consistency of upset are considered proof that all welds are essentially identical. This implies that a destructive test of one item should be sufficient. This, however, assumes a material consistency which we know does not exist. Assuming a consistency of energy input, differences in hardness, cross sectional area, alignment, chemical composition, and soundness can produce variations in the weld. Based on past experience, it is felt that all outward signs of a sound weld can exist, but the bond may be unsatisfactory.

The current method used to test welds involves destructive metallurgical and mechanical techniques. One case history involves a 4.2 inch mortar projectile. This item is normally produced by brazing a base and a nose adapter to a piece of thin-walled tubing. Two producers of the round attempted to make components by replacing the two brazed joints with friction welds. These items appeared to be sound, but a subsequent metallurgical examination disclosed that the weldment was extremely hard and possessed very low ductility. After tempering, the weld hardness dropped from Rc 50 to Rc 26, and toughness values reached an acceptable level. Nevertheless, these components left the manufacturer's plant with extremely substandard welds, a condition that could not have been determined non destructively.

Good process control, i.e., assurance that tempering was performed, would solve the brittle weld problem. However, a suitable non-destructive test performed on all items would be desirable for this condition. A much more severe problem would be the presence of discontinuities at the weld interface. This would not only produce an area of weakness, but it would allow leakage or pinching of the high explosive fill. If the discontinuity reaches the surface, it can be detected by several means. However, a subsurface defect might be impossible to find. To date, most of the resistance to the use of friction welds for ammunition components is based on this factor.

Several years ago, while evaluating the use of resistance welding for joining of burster casings to chemical munitions, we noted a phenomenon which could be of some use. When post heat was applied to the resistance weld by the resistance welder, a heat ring was formed on one side of the weld representing the extent of surface oxidation. This ring was usually uniform. However, where a discontinuity existed in the weld, it was accompanied by a jog in the heat ring. This jog was caused by non uniform heat conduction through the weld. Since electrical and thermal characteristics are related, it is suggested that a type of conductivity test be used to detect weld discontinuities. A refinement of the technique may ultimately permit detection of untempered microstructures as well. However, we are not familiar with any equipment capable of performing these tests.

Commanding Officer, Frankford Arsenal
Philadelphia, PA
ATTN: E. E. Dougherty

SUMMARY REPORT OF PROBLEM NO. 6

DEVELOPMENT OF A TECHNIQUE TO DETERMINE SOUNDNESS OF FRICTION WELDS IN HIGH EXPLOSIVE MUNITIONS

J. F. Erthal
Problem Coordinator

1. After friction welding, the outside surface is machined to remove the excess metal at the joint. The inner surface is not machined to remove the excess metal.

2. Two conditions of this weld are of prime concern, namely, ductility and freedom from subsurface discontinuities at the weld junction. The ductility is obtained by post-weld tempering which reduces the weld hardness from R_C 50 to R_C 26.

3. Post-paper comments and suggestions for solving this problem were:

E. Roffman, Frankford Arsenal - Suggested the acoustical analysis approach for weld discontinuities.

E. Barnes, Picatinny Arsenal - Recommended infrared method immediately after welding for bond or joint integrity.

J. Turbitt, Naval Torpedo Station
R. Brachman, Frankford Arsenal - Suggested X-ray diffraction for detecting untempered martensite.

M. Weinberg, Picatinny Arsenal
S. Hart, NRL - Suggested ultrasonic shear wave for subsurface discontinuities at the weld junction.

4. During the problem discussion period, the following suggestions were made:

E. Deemer, NAVAIRSYSCOMREPLANT - Suggested magnetic perturbation method for weld integrity.

D. Polansky, NOL - Recommended isotope radiography IR $_{192}$ with crystal for counting as a technique for bond or joint integrity.

S. Hart, NRL - Elaborated more on his ultrasonic method; namely, use a shear wave at the highest frequency possible with a high angle of refraction or longitudinal waves introduced at the end of the part for lack of fusion or interface detection.

5. Since there was no consensus, I will offer the following for thought concerning this problem:

a. Eddy current inspection should assure that the weld was heat treated or tempered.

b. With respect to subsurface discontinuities at the weld junction, acoustic analysis, ultrasonics, magnetic perturbation, or isotope radiography are all methods to consider to solve this problem. The selection, of course, will depend upon the availability of equipment and familiarity with the method.

J. F. Erthal
NAVAIRDEVCEN
Aero Materials Department
Warminster, PA 18974

FORMAL PAPERS

PAPER #1

AN OVERVIEW OF THE NONDESTRUCTIVE TESTING AND INSPECTION PROGRAM AT THE NAVAL AIR REWORK FACILITY JACKSONVILLE. FLORIDA

F. W. THOMAS AND W. D. ORDERS

NAVAL AIR REWORK FACILITY

JACKSONVILLE, FLORIDA

ABSTRACT

The requirements of the Navy for the highest possible degree of fleet readiness, aircraft structural integrity, and reliability have imposed an increasing demand on the use of nondestructive inspection methods. In order to support compliance with these requirements, the Naval Air Rework Facility at Jacksonville, Florida has augmented it's nondestructive inspection programs. Primarily, emphasis has been placed on developing nondestructive inspection procedures which will reduce the cost of aircraft reconditioning and maintenance through the reduction of disassembly for inspection. Nondestructive inspection is one of the major facets of the Analytical Rework Program, where deep structural inspections are accomplished on a sampling basis. A number of nondestructive inspection techniques have been developed and applied in support of the Periodic Aircraft Rework and the Analytical Rework Programs. Efforts have been made to select the optimum nondestructive inspection techniques and equipment for solution of these problems. Present and projected cost savings realized from the application of nondestructive inspection have significantly reduced operating costs at the Naval Air Rework Facility, Jacksonville. This paper presents an overview of the nondestructive inspection program at the naval air rework facility. The theme is the relationship of people, facilities, equipment, instructions, and applications for nondestructive in ection of aircraft components.

Examples of equipment, and fixtures and methods developed by the naval air rework facility, will be shown to illustrate how cost can be reduced through their use. Several specific inspection problems will be discussed along with the nondestructive inspection techniques and equipment employed for solution of these problems.

PAPER NO. 1

AN OVERVIEW OF THE NONDESTRUCTIVE TESTING AND INSPECTION PROGRAM AT THE NAVAL AIR REWORK FACILITY JACKSONVILLE, FLORIDA

F. W. THOMAS AND W. D. ORDERS

NAVAL AIR REWORK FACILITY

JACKSONVILLE, FLORIDA

The requirements of the Navy for the highest possible degree of fleet readiness, aircraft structural integrity, and reliability have imposed an increasing demand on the use of nondestructive inspection methods. In order to support compliance with these requirements, the Naval Air Rework Facility at Jacksonville, Florida, has augmented it's nondestructive inspection programs. Primarily, emphasis has been placed on developing nondestructive inspection procedures which will reduce the cost of aircraft reconditioning and maintenance through the reduction of disassembly for inspection. Nondestructive inspection is one of the major facets of the Analytical Rework Program, where deep structural inspections are accomplished on a sampling basis. A number of nondestructive inspection techniques have been developed and applied in support of the Periodic Aircraft Rework and the Analytical Rework Programs. Efforts have been made to select the optimum nondestructive inspection techniques and equipment for solution of these problems. Present cost savings realized from the application of nondestructive inspection have significantly reduced operating costs at the Naval Air Rework Facility, Jacksonville; projected cost savings will further reduce operating costs.

The nondestructive inspection program of the Naval Air Rework Facility in Jacksonville, Florida (NAVAIREWORKFAC JAX) is accomplished by an integration of people, equipment, and available facilities.

The most important asset of the NDI Program is, of course, the skilled personnel participating. Within the Production Department, under the NDI supervisor, there are

twelve inspectors certified for eddy current, ultrasonic, magnetic-particle, and penetrant inspections. Five of these twelve are also certified for X-ray inspection. There are two technicians in the Quality and Reliability Assurance Department who are concerned with inspector certification and NDI process review. In the Weapons Engineering Department, there are two engineers and three engineering technicians who devote a majority of their time to the development of NDI procedures. Available facilities for accomplishment of the nondestructive inspection program include an area in the Materials Engineering Laboratory, used for technique development and two magnetic-particle inspection lines, two fluorescent-penetrant inspection lines, and a hangar area designated for X-ray inspection work. The temporary assignment of an A-7 aircraft for use as a test-bed for development of NDI procedures has been a most valuable asset.

A wide range of types of NDI equipment produced by various manufacturers is used in the NDI program. This equipment includes eddy-current instruments, ultrasonic instruments, thermal, magnetic-particle inspection equipment, fluorescent-penetrant inspection kits, X-ray equipment, and various optical aids such as fiberscopes, borescopes, and otoscopes.

A large portion of our inspection workload is accomplished utilizing fluorescent magnetic-particle and fluorescent penetrant. Recently, the NAVAIREWORKFAC installed a large fluorescent-penetrant inspection system, engineered by Magnaflux Corporation. The system will handle a single, large, heavy aircraft component or loads of smaller components up to 5,000 pounds in weight and 5 x 6 x 5 feet in size. The high capacity of the system has reduced inspection cost considerably. Items inspected for surface defects include all nonferrous engine cases, landing gear parts, aircraft structural components, turbine blades and disc_, as well as ground handling equipment parts and tooling.

The system consists of a series of processing stations connected by heavy-duty roller conveyors. Moving along on a programmed schedule, aircraft parts are raised and lowered on roller grilles into processing tanks.

Testing starts when the clean part, at room temperature, is lowered into a tank holding fluorescent penetrant. Then, it moves to the drain area where it drains for a specified time.

Next, the part, held on a grille, is lowered into a tank filled with emulsifier, which makes the penetrant water-washable. From there, the part travels to an agitating grille in the dip rinse station where water removes most of the penetrant. Any penetrant that remains is washed away at the spray-rinse station, which features a 360° turntable.

At the drying station, recirculated warm air removes moisture from the part, preparing it for the dry developer station. There, a cloud of dry developer is created and allowed to settle on the part. Any developer remaining is drawn off in a dust collector before the chamber doors are opened, and the part is rolled into the inspection booth. At the booth, four 400 w and four 100 w black lights shine down on the part, revealing surface defects. Parts that pass the test are given a final spray-wash, and placed back into service.

An average of 5,000 parts are processed daily through the fluorescent-penetrant and fluorescent magnetic-particle inspection lines; approximately 40 defective parts are discovered daily - most of which are repaired and made ready for service.

We operate a total of nine X-ray units. There are five 140KV Sperry units, one 140KV Balteau, a 160KV continuous duty cycle Sperry unit, a 50KV Balteau, and a Phillips 300KV constant potential continuous duty cycle unit. Film processing is accomplished with a KODAK X-OMAT automatic developing system.

The bulk of our ultrasonic inspections employ either the Sperry UM 715 or the more portable UCD reflectoscopes. A few pieces of Magnatest and Krautkramer equipment are also used. Many of our ultrasonic transducer contour shoes and support fixtures are locally manufactured.

Eddy current inspection, an inspection technique well established throughout the NDI community, is a well established inspection technique at NAVAIREWORKFAC JAX. Since all eddy current instruments have different characteristics, we have invested in various types of eddy current equipment, such as the NORTEC NDT-2 instrument, using differential coil probes, which is an ideal instrument for detecting cracks in threaded fastener holes. The Magnatest ED 500 is early vintage equipment that still has many applications. The NORTEC NDT-3 is used for detecting cracks in ferrous and nonferrous metal alloys and for evaluating jet engine tail pipes for susceptibility to corrosion. The eddy current "workhorse" is the light-weight battery-powered

Magnatest ED 520 used primarily for crack detection in nonferrous metal alloys. The NORTEC NDT-110 conductivity meter is used to determine heat treat condition in nonferrous metal alloys and for evaluating aircraft structural components for heat damage. The majority of eddy current instruments are battery powered. A wide assortment of eddy current probes and coils are in our inventory.

A recent equipment acquisition has been a thermal inspection system manufactured by Automation Industries, Incorporated, used for detection of disbonds in laminated structural components.

When crack defects are discovered, an RCA electron microscope is often used to perform electron fractography investigations in order to determine the defect formation mode.

For effective application of equipment, accurate and reliable inspection procedures must be developed. Procedure development requires the coordinated efforts of engineering and shop personnel. Inspection techniques are developed and proven prior to the issuance of engineering instructions for accomplishing the inspections. A typical written engineering instruction issued by the Weapons Engineering Department will contain equipment set-up parameters, drawings, or references to drawings to depict the specific area for inspection as well as specific detailed instructions for probing media placement and movement. Acceptance/rejection criterion and instructions for interpretation of instrument presentations are also given. In most cases, the engineering instruction recommends an alternate NDI method as a back-up for defect verification when defect indications were obtained from the primary method.

In support of technique development, special fixtures and accessories such as eddy current probes and ultrasonic contour shoes are locally designed and manufactured. Our recently attained capability to manufacture eddy current probes has been a most beneficial support to the eddy current program. Nondestructive inspection programs cannot benefit production until personnel, equipment, and procedures are adapted to productive applications. A few examples of how NAVAIREWORKFAC JAX has made productive applications of NDI for support of aircraft reconditioning and maintenance programs will now be presented.

Manufacturing defects established a need for a procedure to inspect the internal structure of the horizontal stabilizer on the A-7 aircraft. X-ray was selected as the optimum technique to detect buckling and radius cracks in internal rib members. Our portable 140KV Sperry X-ray unit was used for this job.

The aircraft Analytical Rework Program dictates structural inspection requirements for selected areas on a sampling basis. One inspection requirement is the examination of the A-7 aircraft fuselage structure at specific fuselage frame stations. An X-ray inspection technique was established, using the 140KV Sperry unit. The tubehead was placed on the inside of the engine air intake duct. Film placement for these inspections is on the outside of the fuselage.

Prior to the development of an ultrasonic inspection procedure for the A-7 landing edge flap hinge it was necessary to remove the flap, strip paint, perform penetrant inspection, reinstall and rig the system. An ultrasonic inspection using a portable Sperry UCD instrument with a specially designed transducer shoe provides a more sensitive inspection without requiring disassembly. Ultrasonic inspection of the flap hinge requires 6 man-hours per aircraft; conventional inspection requires 80 man-hours per aircraft.

There are numerous fuselage attach fittings for landing gear components. These fittings require inspection during aircraft rework because of the high-stress loading and the criticality of the parts. Fittings inspected with ultrasonics include arresting gear attach fittings, main and nose landing gear attach fittings, and the drag link attach fittings. Ultrasonic inspection of these attach fittings, provides a more sensitive inspection of critical structural members where catastrophic failure will most probably be initiated. These inspections can be accomplished without paint stripping and disassembly.

The NORTEC NDT-110 ultrasonic thickness-gage is used to evaluate A-7 aircraft center windshield frames for corrosion damage. The windshield frame is a magnesium alloy casting. Due to water entrapment, severe corrosion can occur on the underside (between the windshield and an overlapping flange) of the frame. An acceptance/rejection criteria was established using corroded frames for calibration standards. A significant man-hour savings was realized through the application of the ultrasonic inspection technique. Ultrasonic inspection of the windshield frame requires 0.5 man-hours per aircraft. Frame removal and reinstallation for visual inspection of the frame requires 70 man-hours per aircraft.

Due to a manufacturing error in the wall thickness of an unknown quantity of the A-7 main landing gear shock strut end caps, instructions were received to perform a one-time inspection of all such items in our local area. An ultrasonic inspection was developed for measuring wall thickness. The inspection was performed on disassembled and assembled parts. All parts

inspected were within the design requirements. Without the inspection capability to accurately determine part wall-thickness when only one side of the part is accessible, excessive disassembly and reassembly would have been required.

A portion of the reconditioning work performed on R1820 reciprocating engines requires inspection of sodium-filled valves for small fatigue cracks on the inner walls. The inspection is accomplished with a system engineered by Magnaflux Corporation, employing the PS-902 ultrasonic pulse unit, plus a special fixture and transducer assembly. Held in the fixture and immersed in kerosene, the valve is rotated while the technician positions the transducer manipulator for inspection of critical sections inside the valvehead and stem. The system is sensitive enough to detect cracks as small as 0.005 inches wide and 0.006 inches deep and is capable of an inspection rate of one valve a minute. The system is gated so that a red light and buzzer signal is presented when critical cracks are present.

In the past 3 years, the use of eddy currents as a probing media for inspection has increased by several-fold. The Magnatest ED-520 eddy current instrument has been successfully employed to detect incipient failure of A-7 wing pylon fittings. Small, sub-critical stress-corrosion cracks can be detected in the 7075-T6 aluminum alloy forgings.

Eddy current inspection of aircraft wheels is being used throughout the Navy. The NAVAIREWORKFAC is currently providing on-the-job training for fleet personnel on field eddy current inspection of aircraft wheels.

One of our most beneficial applications of eddy current inspection was the inspection of hydraulic cylinders which control the movement of the horizontal stabilizers on one of the Navy's first-line attack aircraft. Inspection of these hydraulic cylinders on every aircraft of a particular model was required when a series of cylinder failures resulted in aircraft accidents. Failure analysis revealed that the cause of cylinder failure was fatigue cracking originating at bleed ports which are drilled and tapped holes located in the forging parting line. The cracks originated at a point where the drilled port hole intersected the inside wall of the cylinder. The inspection technique developed at NAVAIREWORKFAC JAX employed a NORTEC NDT-2 eddy current instrument using a differential coil probe which was capable of detecting cracks 0.03 inches deep and 0.12 inches long, a crack size well below the critical crack size. The

inspection was performed with cylinders in place on the aircraft, the only required disassembly being removal of port hole plugs. The inspection was accomplished on land- and carrier-based aircraft. Approximately 500 separate cylinders were inspected. Thirty-seven (37) defective cylinders were found. Aircraft crashes were definitely prevented by the detection of incipient cylinder failure. Periodic inspection was accomplished for a time until all old cylinders were replaced with new cylinders of improved design.

With the ever-increasing demand for accurate, cost effective, inspection of critical components in mind, the NAVAIREWORKFAC is constantly updating NDI by evaluating new methods and equipment such as acoustic emission, holography, X-ray radiograph color derivation extraction and techniques to improve equipment mobility and versatility.

In the near future, the NAVAIREWORKFAC inventory of NDI equipment will be supplemented with a completely self-contained X-ray system. The system will consist of a 300KV tubehead mounted at the end of a hydraulic mechanical arm with an effective reach of 35 feet. The complete system, consisting of a power generator, equipment-cooling system, and a lead-lined control cab carried by a 2-ton truck. This equipment will permit a significant reduction in time required to set up for X-ray inspection and will provide high-power mobile X-ray inspection capability, thus opening a new avenue for X-ray inspection of aircraft structures that are too heavy in section for inspection with low-power X-ray.

The developing technology for color derivation extraction for enhancement of X-ray radiographs is being observed by the NAVAIREWORKFAC NDI engineers. The equipment for accomplishing the color extraction, labeled the CODE-R System, is a fully-automatic film processor that will extract, in color, three operator-selected densities from any input radiograph. This equipment will greatly improve inspection reliability, especially in the area of flight safety inspection requirements.

Time does not permit discussion of all the types of NDI equipment and inspection techniques used at the NAVAIREWORKFAC. We, therefore, have dwelled on methods and equipment that currently have the highest frequency of use at the facility. To summarize our program is to say that NDI is playing a major supporting role in assuring that engines and aircraft reconditioned at the NAVAIREWORKFAC in Jacksonville, have the highest possible

cost-effective degree of fleet readiness, aircraft structural integrity, and reliability. This cannot be accomplished with three or four NDI methods, but requires an integrated NDI program employing trained personnel using all methods available.

F. W. THOMAS/W. D. ORDERS
Naval Air Rework Facility (Code 340)
NAS, Jacksonville, FL 32212

PAPER #2

ABSTRACT

Inspection of Aircraft Structure Fastener Holes for Fatigue Cracks by Automatic Eddy Current Scanning

A. P. Rogel, Materials and Test Engineering,
Service Engineering Branch
Sacramento Air Materiel Area (SMAMA), AFLC
McClellan AFB, California

Aircraft structures are subject to fatigue crack propagation in the walls of fastener holes. It is imperative that these cracks be detected before they reach a size that could result in catastrophic failure of the aircraft. NDI methods such as eddy currents, ultrasonics, penetrants, optics, or even x-rays can detect these cracks depending upon the size, location, or aircraft assembly condition. An automatic eddy current system has been developed for reliable detection of cracks that are not easily found by other NDI methods. By periodically scanning the fastener hole and recording the inspection results it has been possible to detect smaller cracks, reduce inspection time, and greatly increase the reliability.

PAPER NO. 2

INSPECTION OF AIRCRAFT STRUCTURE FASTENER HOLES FOR FATIGUE CRACKS BY AUTOMATIC EDDY CURRENT SCANNING

A. P. ROGEL, McClellan AFB, California

INTRODUCTION

Failure of aircraft structural parts has been caused by fatigue cracks in fastener holes. NDT inspection methods are routinely employed to detect these cracks before they can reach a critical size. One of the most common inspection methods to detect these hole cracks is the eddy current technique using a bolt hole probe. This hand scanning technique requires great operator skill to differentiate crack indications from "false" indications due to damaged holes and operator movements. The automatic eddy current system was primarily developed to make the inspection practical and reliable for routine inspection requirements and to use as a substitute for the other NDT methods.

BACKGROUND

Fatigue cracks in fastener holes of critical structural components can result in catastrophic failure of aircraft. Figure 1 shows a typical aircraft part which contains a crack in one of its many fastener holes. These cracks, if they occur in a wing member, usually occur in a forward or aft direction and in the lower portion of the wing surface due to the tension stresses. Figure 2 shows several views of cracks in holes as they develop from short surface fissures to single well-defined cracks. Under certain flight conditions, these small cracks can result in part failure as indicated in Figure 3. Note the positive of the x-ray film of the same crack shown in the figure before the part was removed from the aircraft. Shown in Figure 4 is another view of a failed aircraft part where the crack had grown several inches from the fastener hole before failure. Note the well defined fatigue striations on the cracked surface which require no magnification to be visible. Figure 5 shows the tell-tale identification of fatigue crack where the striations or "beach marks" are clearly visible at 5000X magnification. These figures show a sample of typical crack development in fastener holes that can contribute to aircraft failure.

INSPECTION METHODS FOR CRACK DETECTION

To detect fatigue cracks in holes of aluminum parts when they are quite small (up to .010 in. long and .005 in. deep), a 20-40 power microscope is often used. Because of the poor surface condition

of holes in service aircraft, it is usually necessary to etch the holes prior to this inspection. Penetrants are effective if the foreign material is removed from the cracks by cleaning or etching techniques. A new magnetic rubber technique developed by Convair, Fort Worth Division, is highly effective for holes in magnetic material. Under ideal surface conditions eddy currents is preferred for crack detection when cracks develop to about .015 in. long and .010 deep. Ultrasonics and x-rays are the least sensitive methods for detecting cracks in holes but are advantageous to use in many instances.

AUTOMATIC EDDY CURRENT SYSTEM DEVELOPMENT

The detection of cracks using the microscope and penetrants require extensive hole surface cleaning and tedious effort on the part of the inspector. Eddy current hand scanning techniques as shown in Figure 6 are preferred but the poor surface condition of many fastener holes require great skill to analyze the many crack-like indications during the operation. The automatic eddy current technique was developed to accomplish the following:

1. A substitute inspection method for the microscopic and penetrant techniques.
2. Increase reliability in detection of cracks in service-condition holes over hand scanning techniques.
3. Improve sensitivity of detection of short cracks by making more scans during the inspection.
4. Reduce operator skill and fatigue.
5. Provide a permanent record of inspection results for later examination and verification.
6. Permit crack growth studies in service aircraft or fatigue test programs.
7. Obtain crack depth, length, and orientation data.
8. Insure identical inspection results at all air bases.

After several prototypes of the automatic system were built, the system shown in Figure 7 was developed. The latest systems incorporate additional advances that simplify the entire operation to permit easier signal interpretation. The system as shown was designed and built at McClellan Air Force Base, Sacramento, California. It consists of the following items:

A. A scanner to hold, rotate, and spirally index the bolt hole probe through the fastener hole. Also included is a marker switch to record each 360^{0} revolution of the probe. One end of the scanner is threaded for attaching the unit to the part to be inspected.

B. The control box initiates the scanning operations either to move the probe into or out of the hole. A standard eddy current instrument is mounted in the control box.

C. A strip chart recorder provides a permanent record of the indications noted by the eddy current unit and also records the marker signal.

D. Mounting hardware is provided to attach the scanner to the part being inspected to insure repeatable inspection results. A number of methods are currently in use to attach the scanner to the hole requiring inspection.

E. A built-in calibration standard is mounted in a bracket attached to the scanner to insure proper inspection sensitivity and uniform inspection results at all air bases.

F. The entire system is mounted in a styrofoam padded case to prevent damage of fragile electronic components during field use and transportation.

An illustration of the scanner is shown in Figure 8. Precision fit of the components was required to obtain a smoothly operating unit. The scanner has been thoroughly debugged and is essentially trouble-free.

Figure 9 shows the scanner being attached to the mounting bracket on an aircraft. Each application requires special mounting techniques and tooling. Figure 10 shows the system completely set up and ready to run.

SCANNER OPERATION

Calibration of the entire scanner system is accomplished by using the built-in test standard in the mounting bracket. A disc containing a hole of the same diameter as the fastener hole contains small notches equivalent to the size cracks which must be detected. A recording trace of this standard is obtained prior to inspection of the fastener holes. Trace "A" of Figure 11 shows the test pattern from a calibration disc with notches equivalent to .015 in. and .025 in. deep cracks. Note the large number of individual signals received even though the disc is only .062 in. thick. Each 360^{0} rotation of the probe travels .025 in. along the axis of the fastener hole. Traces "B" and "C" in Figure 11 are traces from cracks

in fastener holes that are shallow (less than .015 in. deep) and deep (greater than .025) respectively. The marker switch was not initiated during these particular tests.

Figure 12 shows a recording trace and the corresponding crack fracture face exposed after the crack was broken open. Note the decrease in amplitude of the trace as the crack becomes more shallow. The length of the crack is closely approximated by counting the number of individual signals and multiplying by .025 in. The orientation (fwd or aft) of the crack is determined from the relation of the notches in the disc standard, its marker signal pattern, and the hole crack signal position with the same marker signal.

RESULTS OF INSPECTIONS AND INVESTIGATIONS.

A. Parts inspection.

Figure 13 shows a trace of a crack detected during a crack investigation program. After sectioning crack it was found to be .050 in. deep and .160 in. long. Initial penetrant and ultrasonic inspections did not reveal this crack.

B. Cracked hole samples.

Figure 14 shows traces from four holes with cracks varying in depth from .015 in. to .090 in. Crack lengths varied from .150 in. to .350 in. These are typical traces.

C. Comparison of cracks found in aircraft groups.

Studies of the same model aircraft at various bases show a wide variation in hole crack development. Figure 15 shows the large number of cracks found in Group B aircraft compared to Group A even though the latter have seen more flying time. This kind of data is easily obtained with the automatic eddy current system. Currently, inspections are made at regular flight intervals to observe small cracks until they develop to a previously determined unacceptable level.

D. Frequency of cracks in sections of a part.

Figure 16 shows the results of a study of a particular series of holes subject to crack development. The holes most susceptible to containing cracks are easily located and corrective action can be initiated. Hole 12 followed by hole 9 are most likely to contain cracks. A fix had been accomplished on hole 10 because of its very high susceptibility to cracks and it could not be inspected for this study.

E. Crack depth data in a series of holes.

Figure 17 shows a part that had undergone fatigue testing. Eddy current inspection showed which holes were cracked, the depth of the cracks, and their lengths.

F. Plot of crack depth.

Figure 18 shows an initial plot of depth of crack vs signal amplitude in a number of cracked holes. Additional samples are being sectioned to obtain a more accurate relationship.

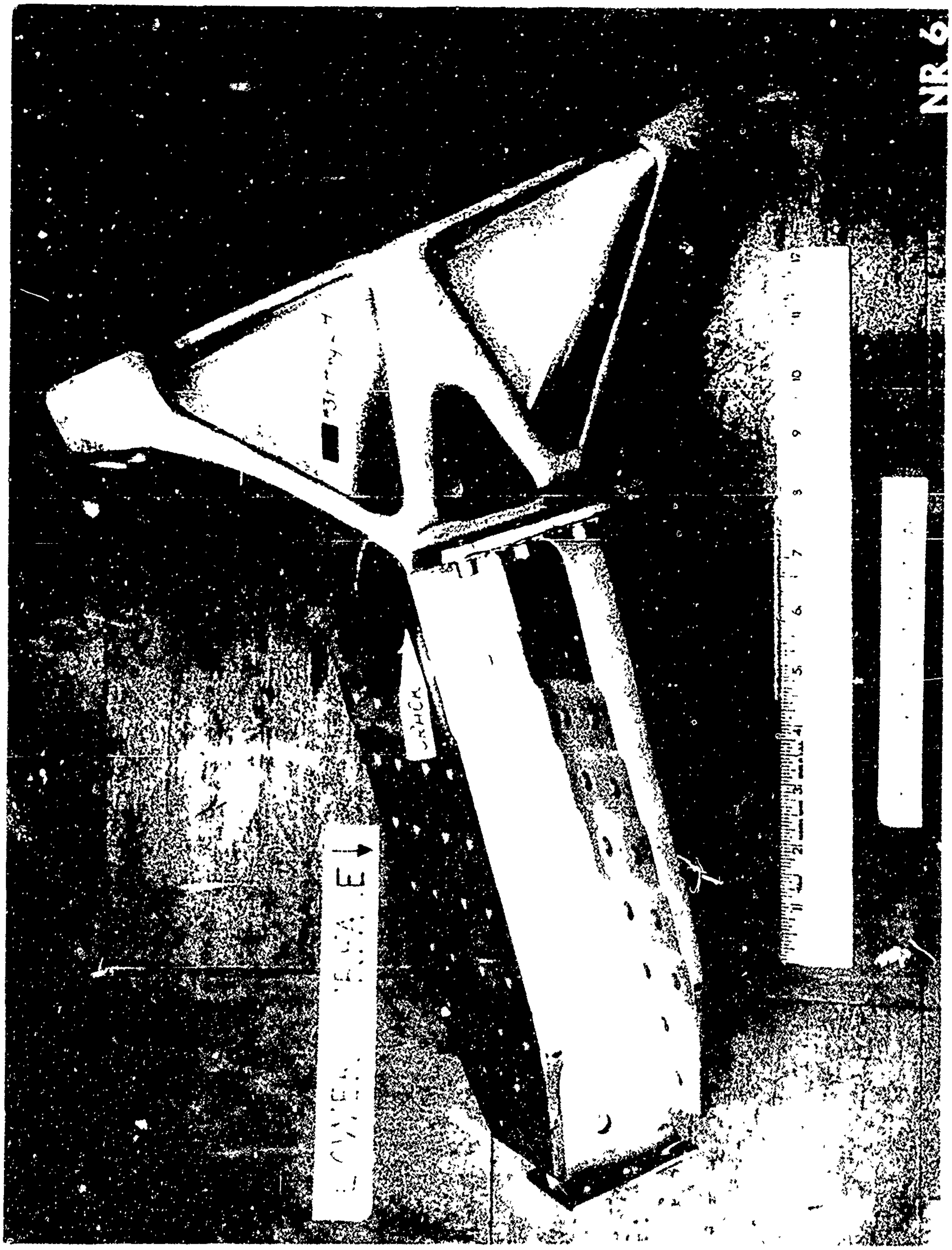
G. Fatigue testing studies.

The automatic eddy current system has been extensively used to detect cracks and their propagation during fatigue testing. A typical series of traces showing the increase in crack depth and length is shown in Figure 19. Previous attempts to gather accurate data by penetrant tests were largely unsuccessful. Eddy current inspections were made at regular 50 hour intervals.

SUMMARY

The automatic eddy current system has been thoroughly tested in field, laboratory, and fatigue testing programs. It has received high acceptance by those actively using the system. Compared to hand scanning techniques, the automatic system makes eddy current inspection an enjoyable task. As the system is being more widely used, continual improvements are being suggested and incorporated as rapidly as possible. Engineering personnel and management are rapidly becoming aware of the value of the data produced by the inspection system and are making decisions based on this information. For those of you concerned with crack detection in fastener holes, the automatic eddy current system will provide a reliable and fast means of gathering inspection data.

A. P. ROGEL
Materials Engineering
Building 250G NMET
McClellan AFB, California 95652


NR 6

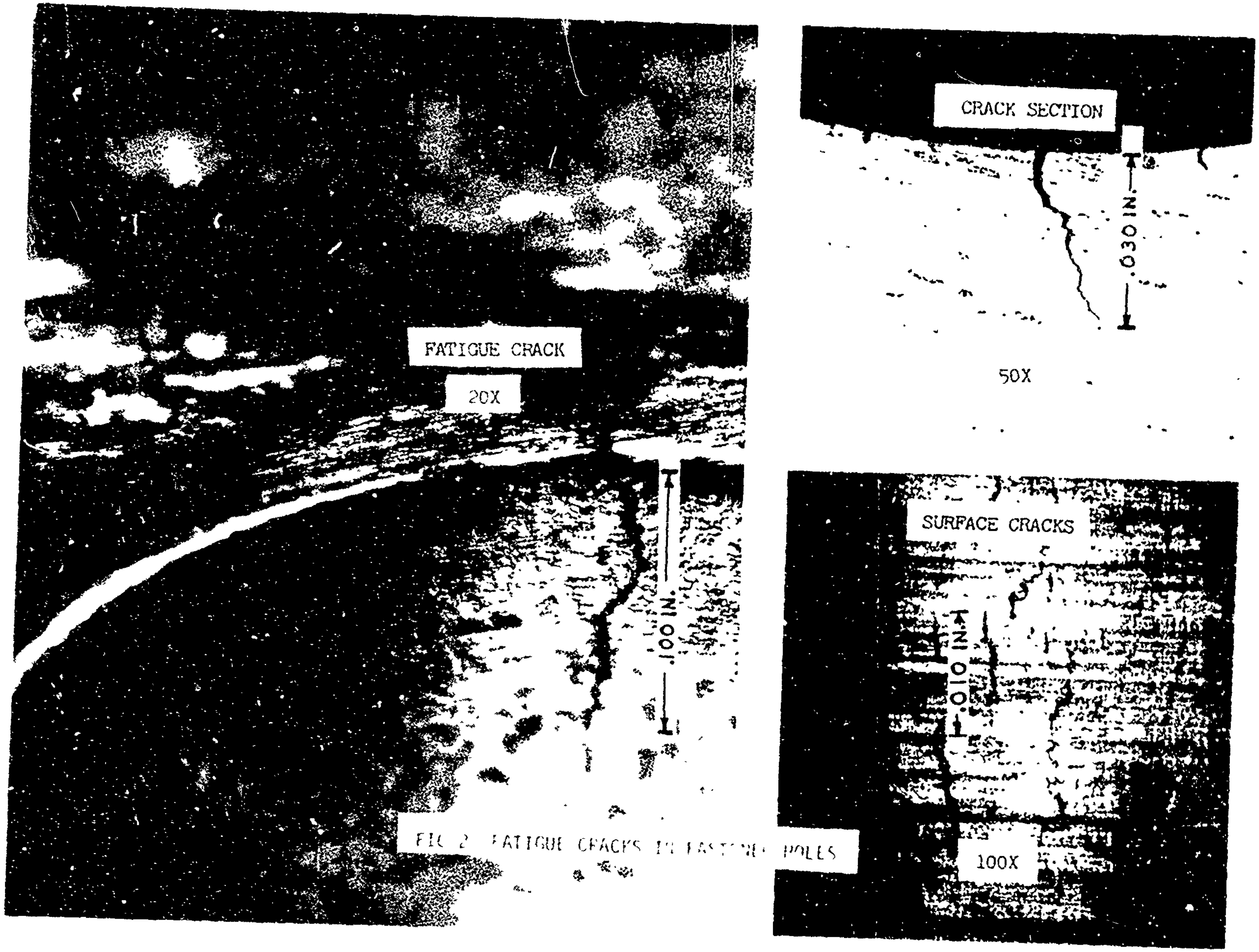


FIG 2 FATIGUE CRACKS IN FASTENER HOLES

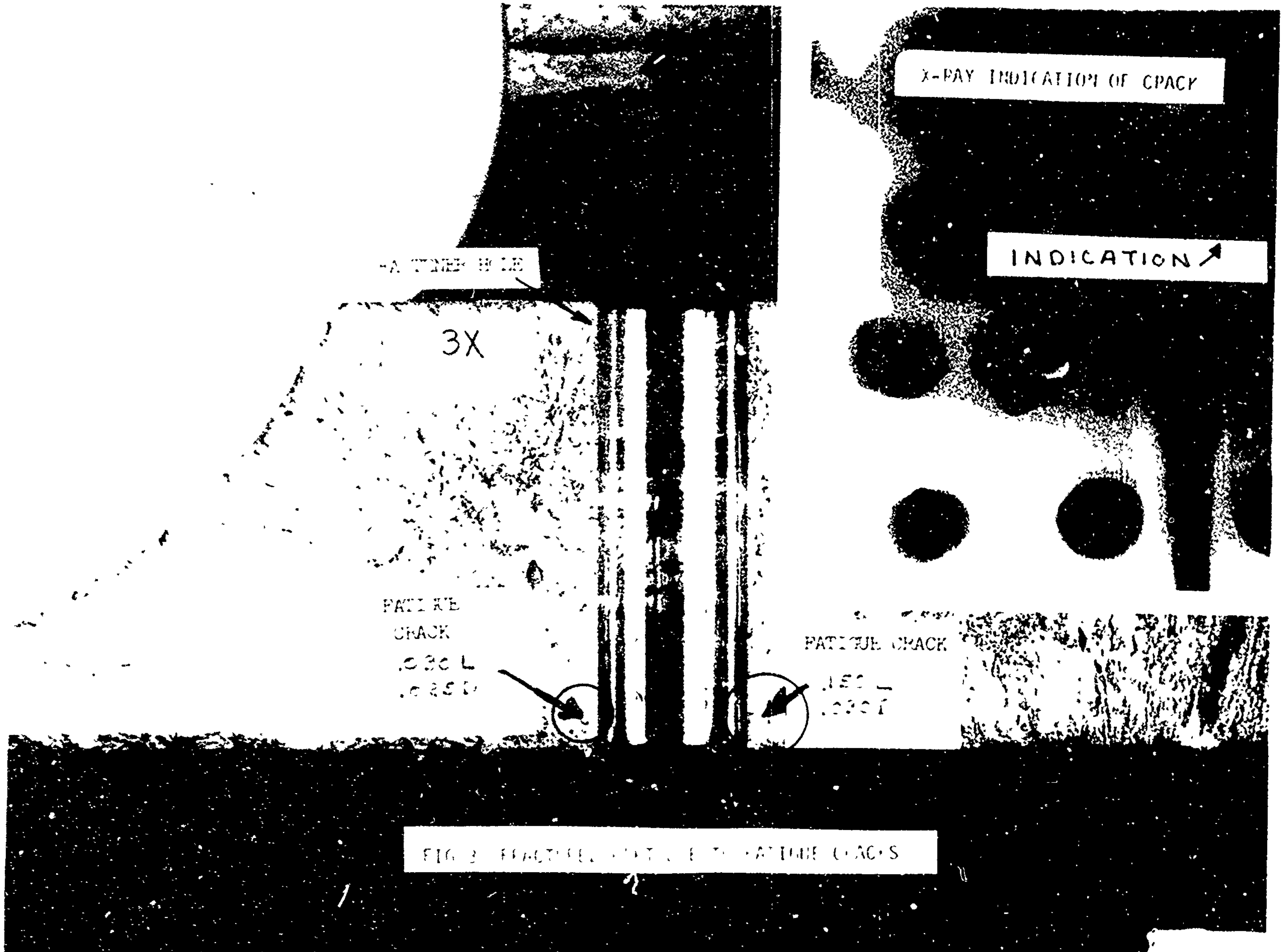


FIG 3 FRACTURED [illegible] FATIGUE CRACKS

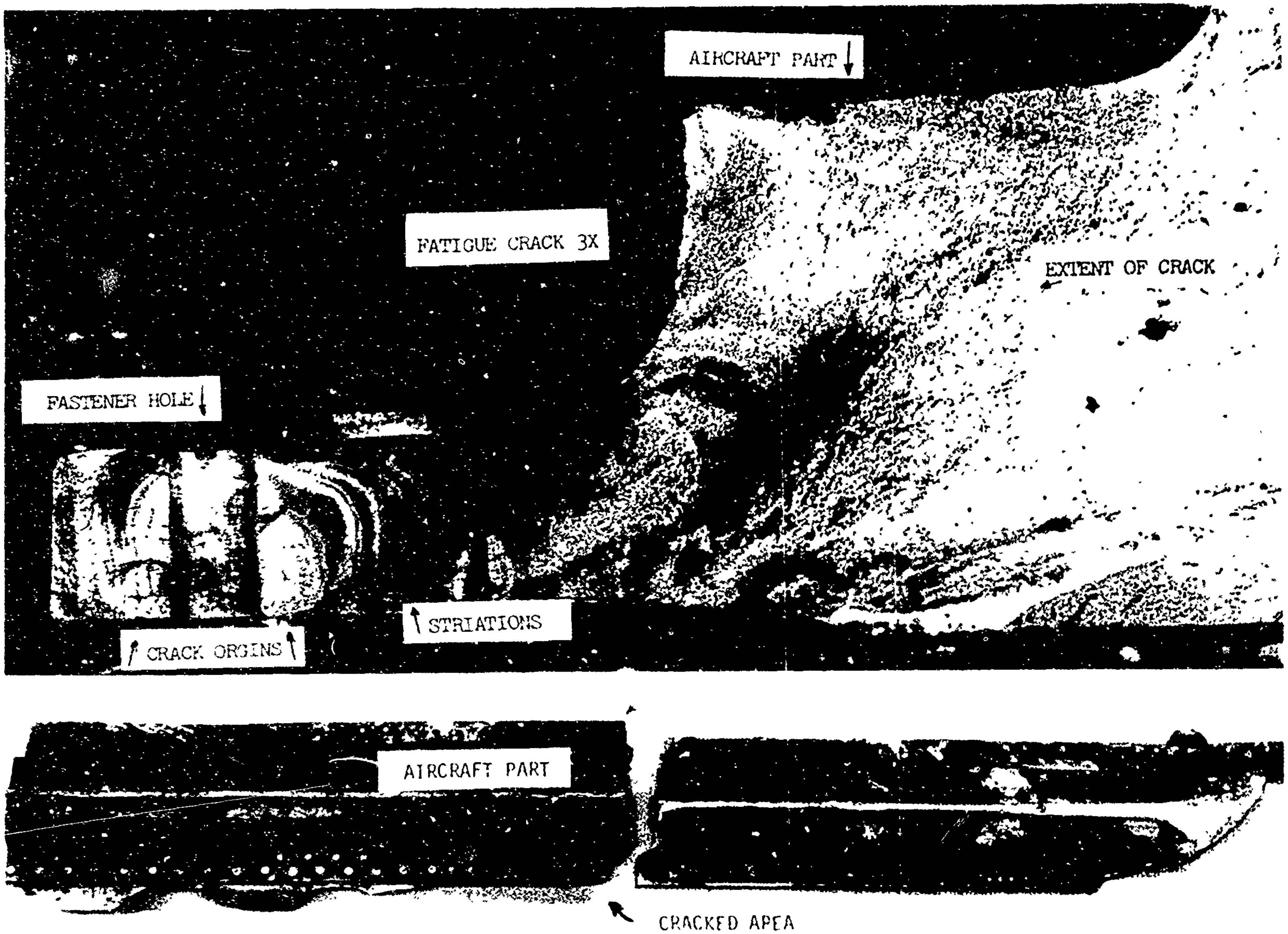


FIG 4 CRACKED STRUCTURAL MEMBER

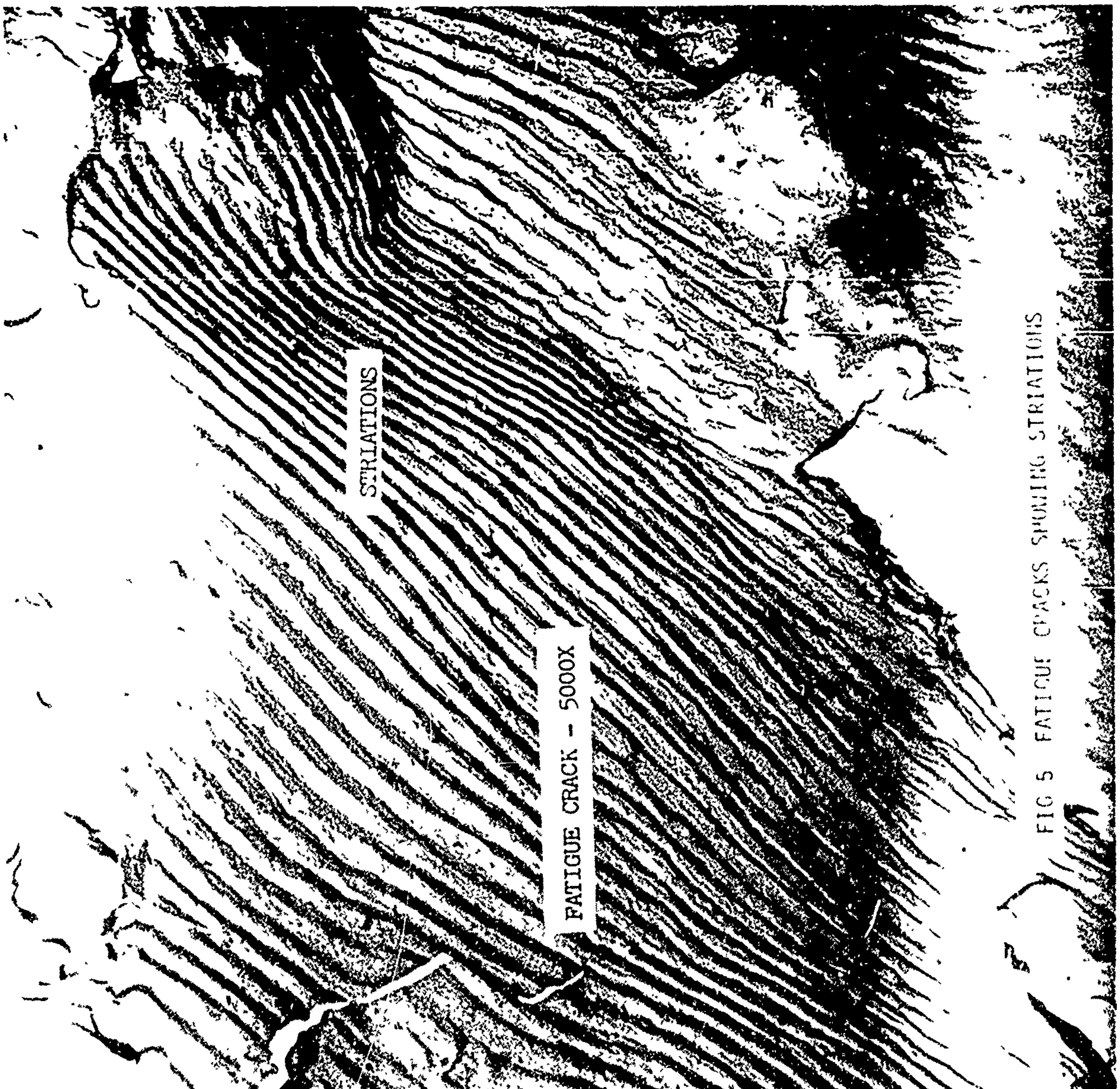


FIG 5 FATIGUE CRACKS SHOWING STRIATIONS

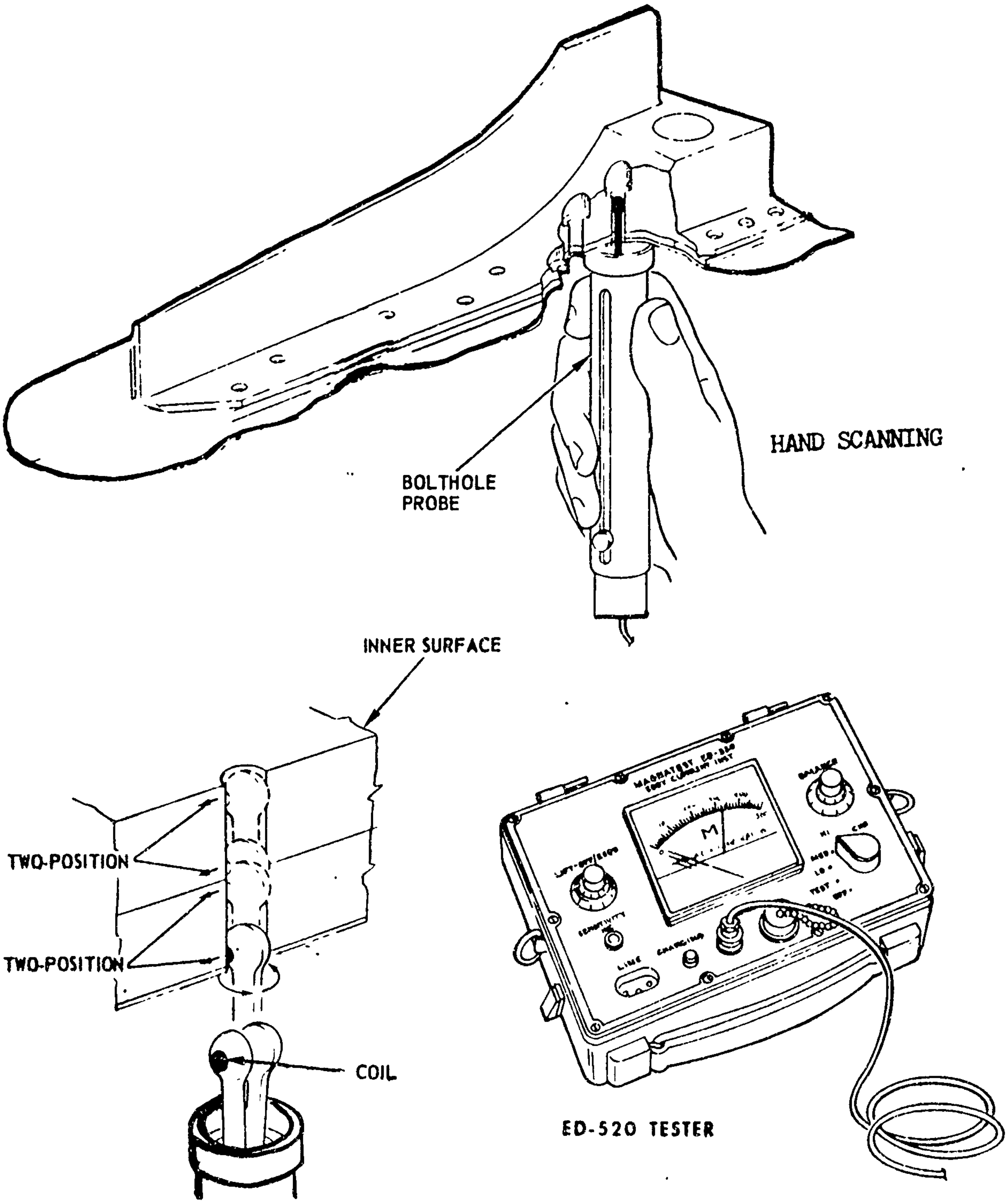


FIG 6 HAND EDDY CURRENT TECHNIQUE

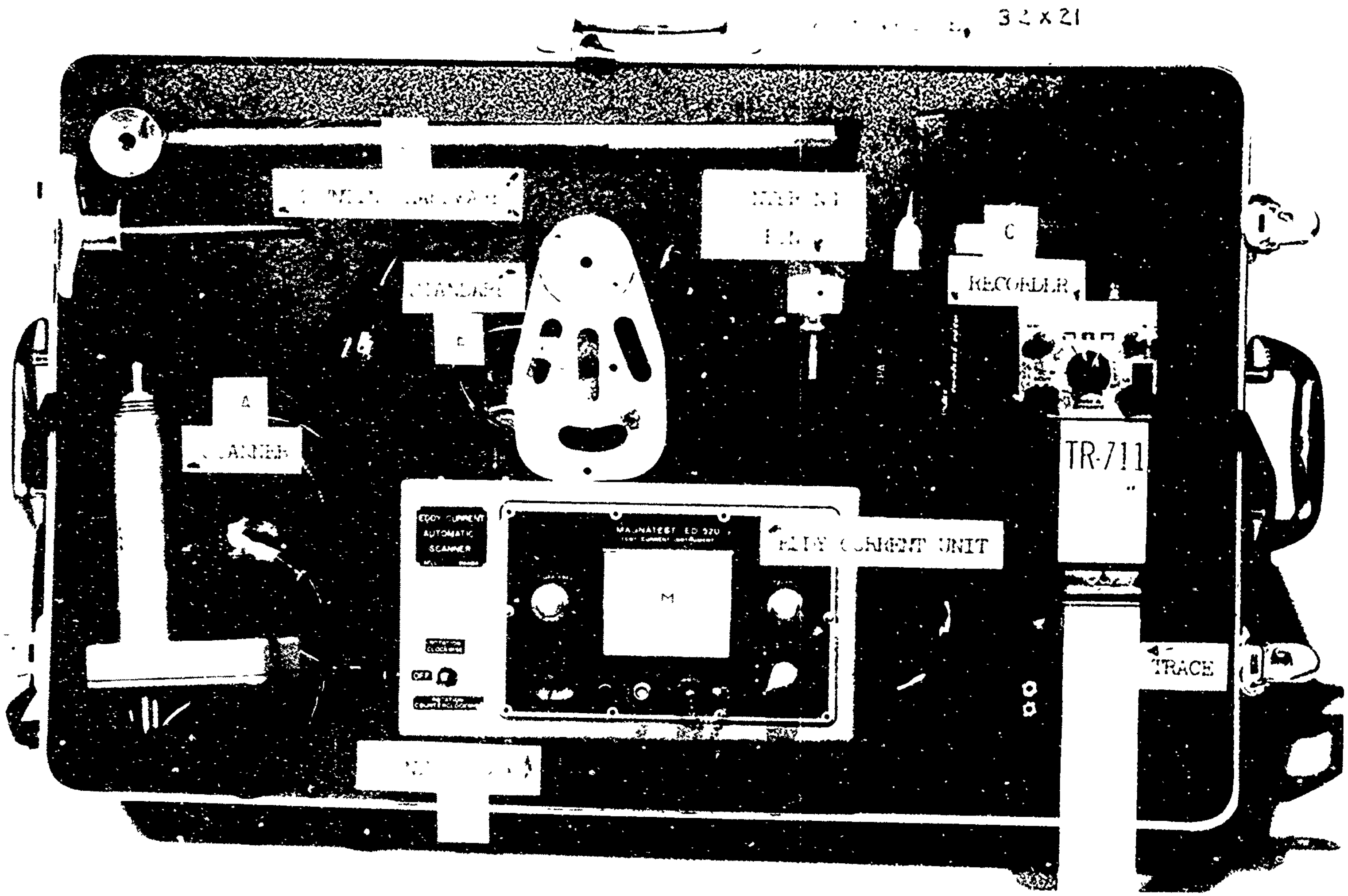


FIG 7 AUTOMATIC EDDY CURRENT SYSTEM

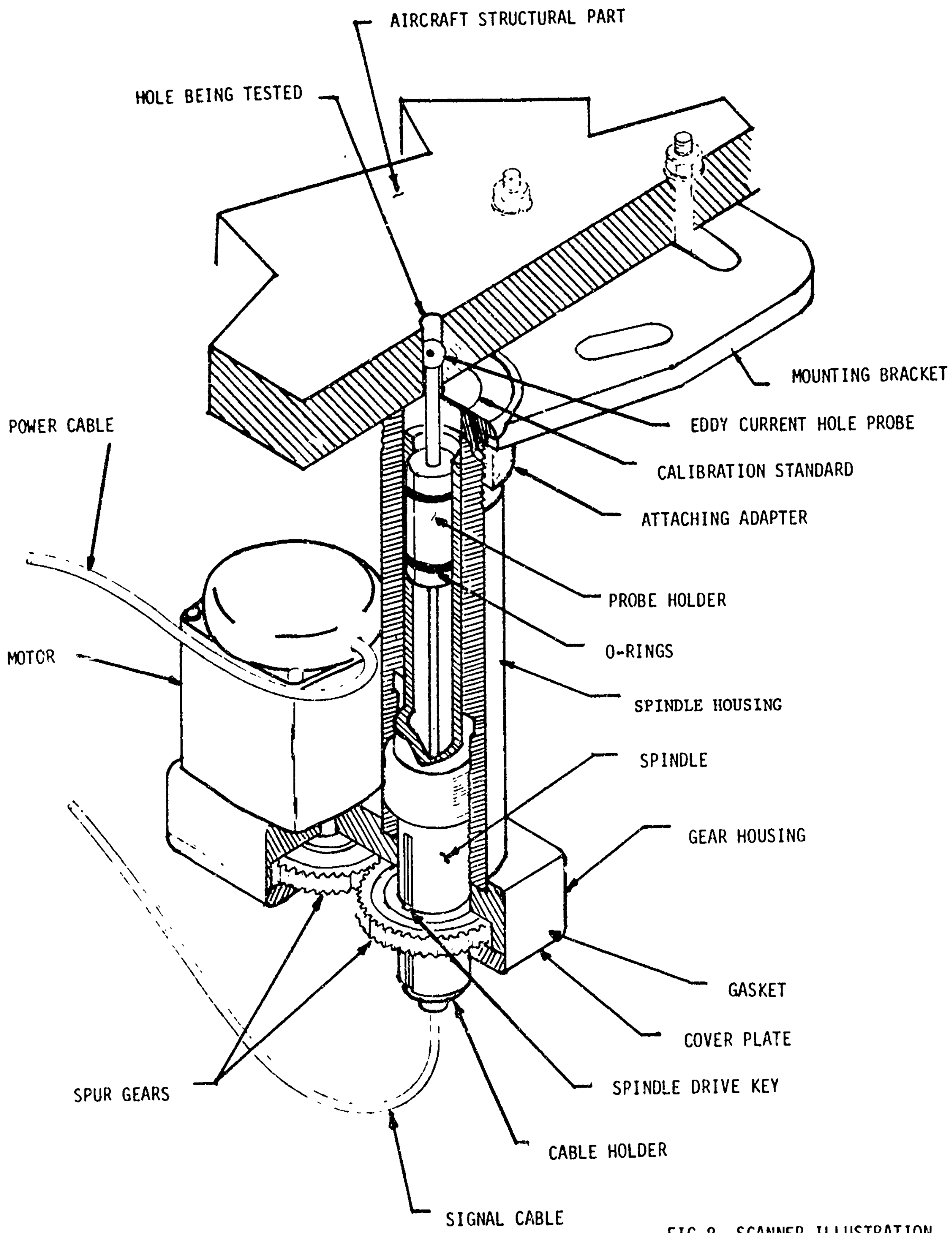
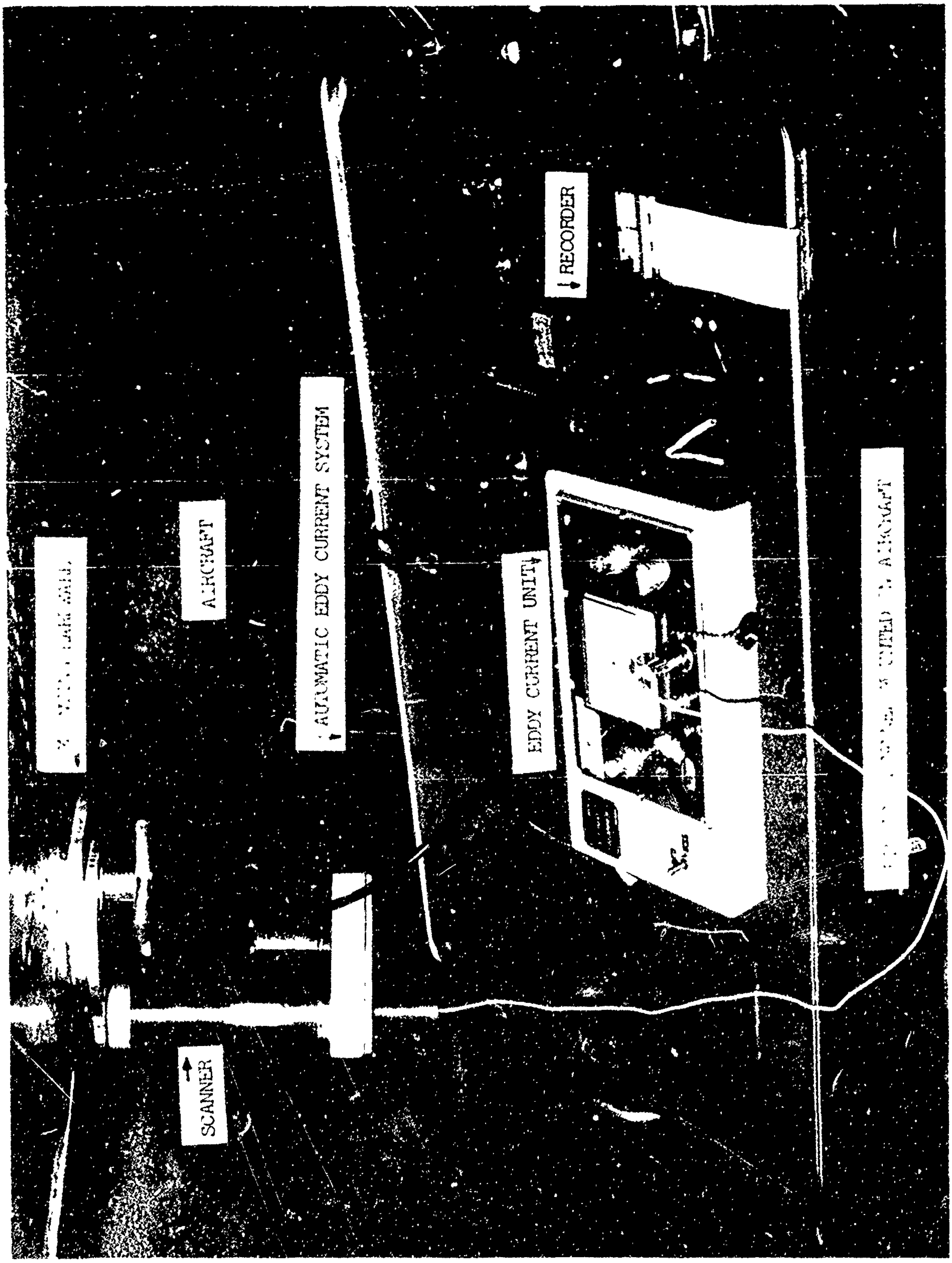


FIG 8 SCANNER ILLUSTRATION

FIG 9 ATTACHING SCANNER TO AIRCRAFT


AIRCRAFT
AUTOMATIC EDDY CURRENT SYSTEM
RECORDER
EDDY CURRENT UNIT
SCANNER

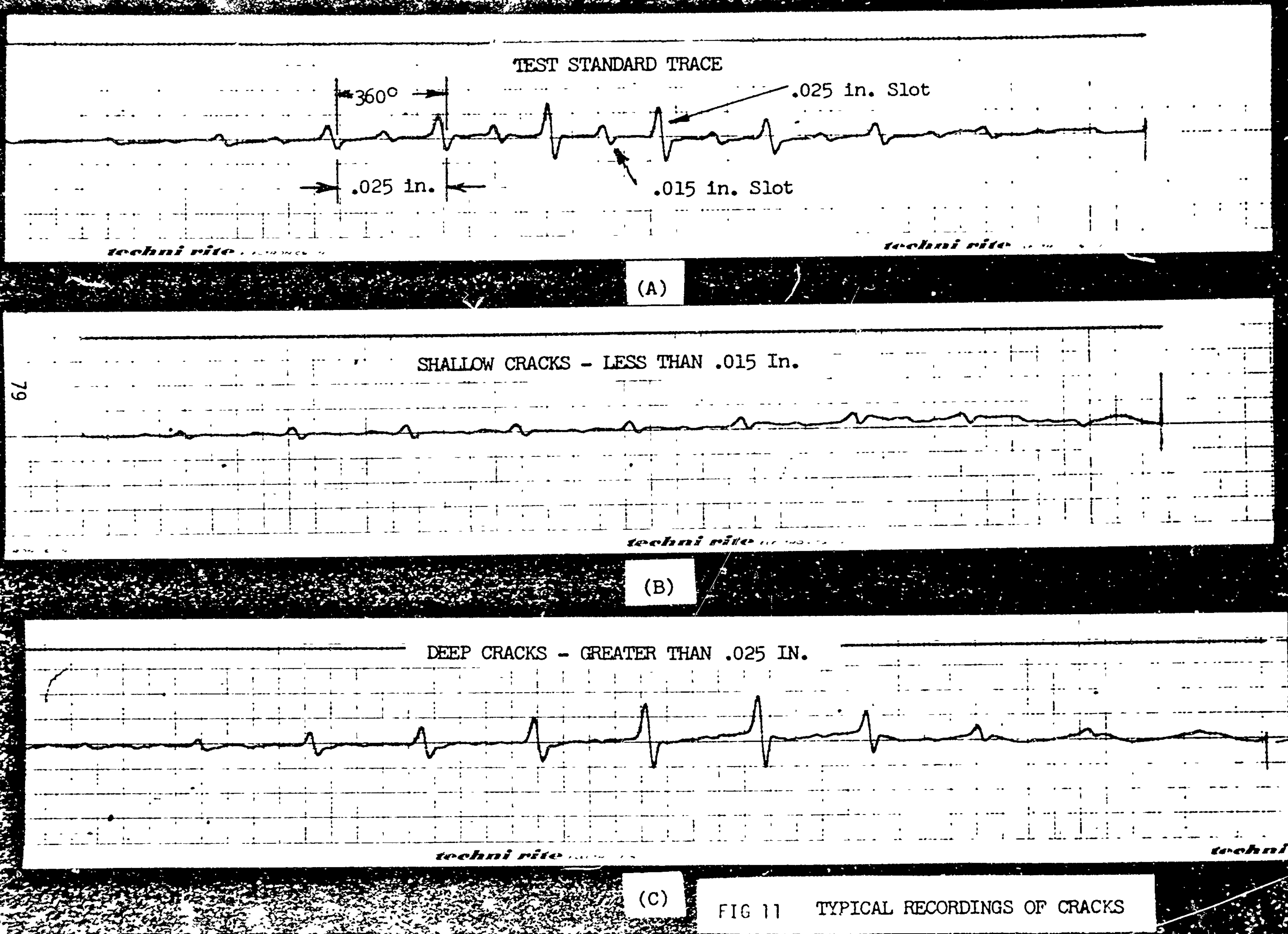


FIG 11 TYPICAL RECORDINGS OF CRACKS

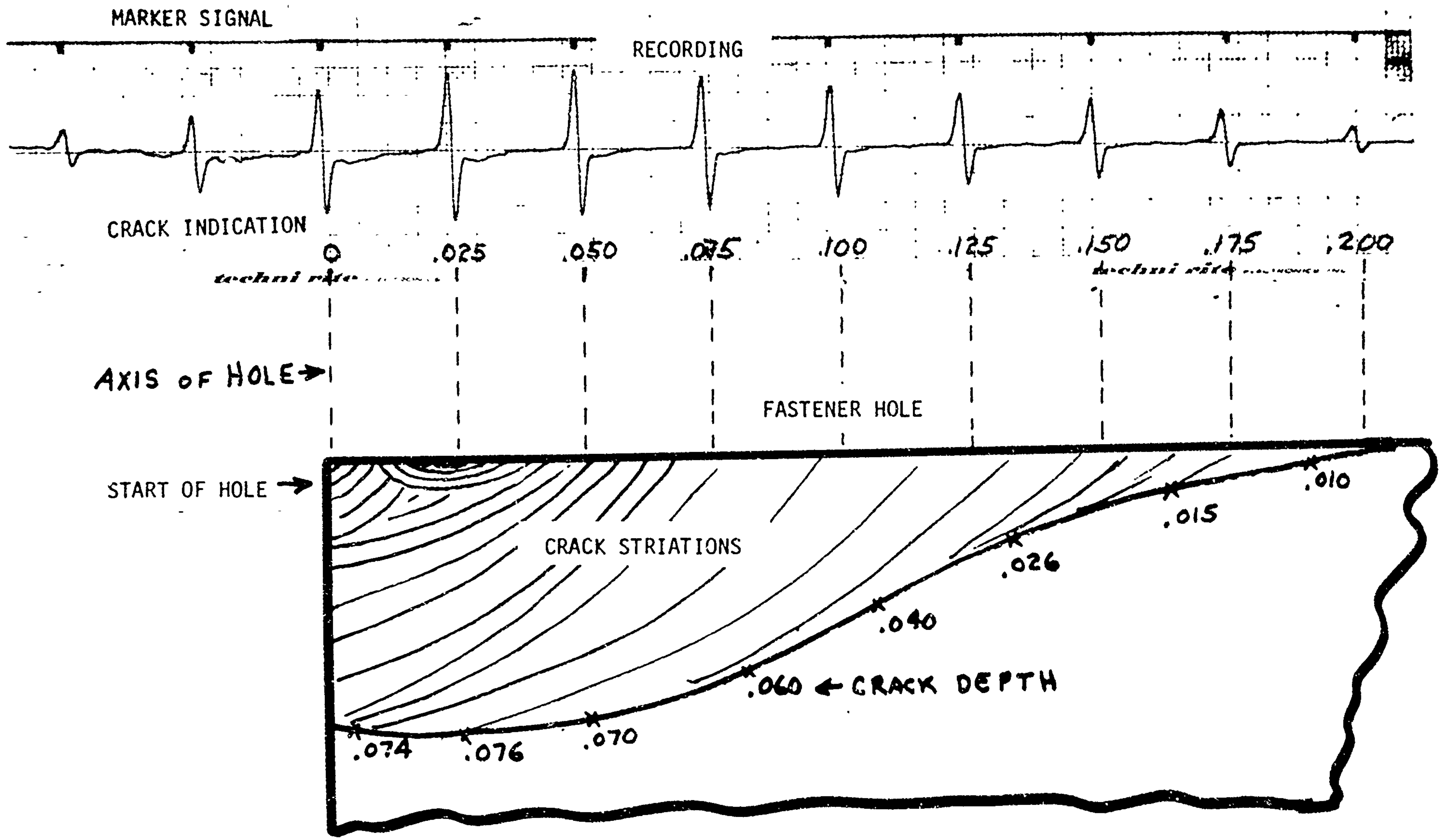


FIG 12 RECORDING TRACE AND CRACK SECTION

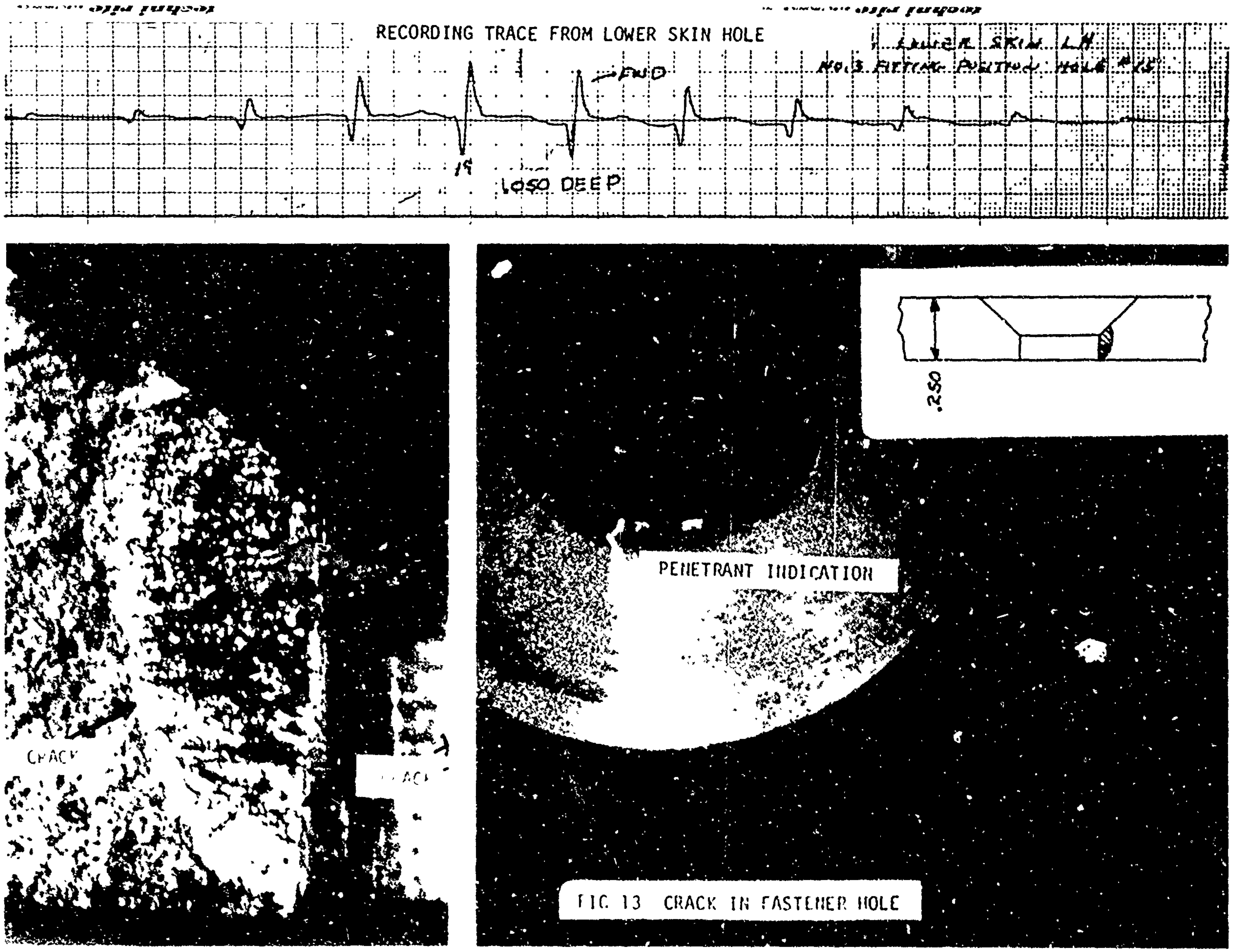


FIG 13 CRACK IN FASTENER HOLE

FIG 14

TYPICAL EDDY CURRENT TRACES

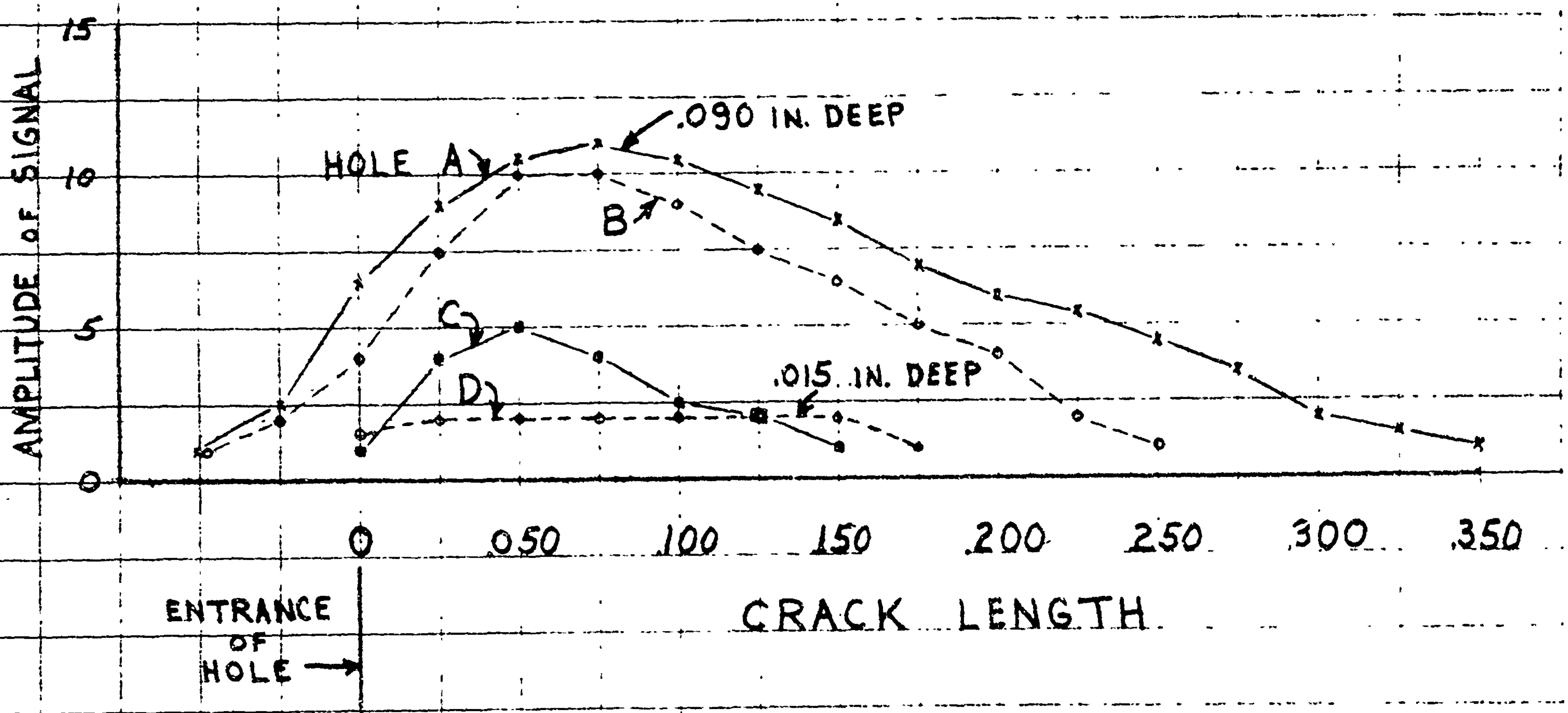


FIG 15

COMPARISON OF CRACKS IN HOLES

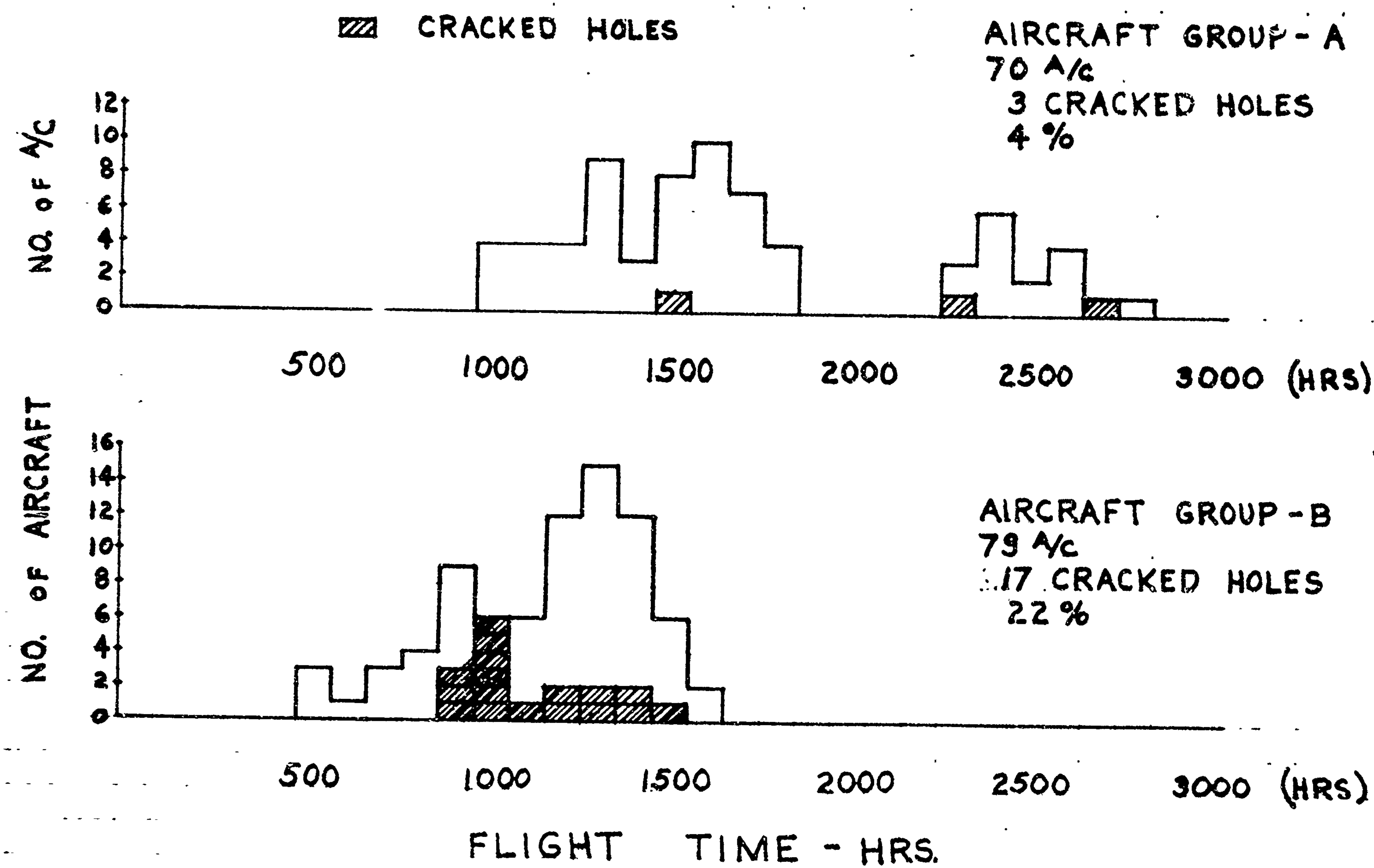
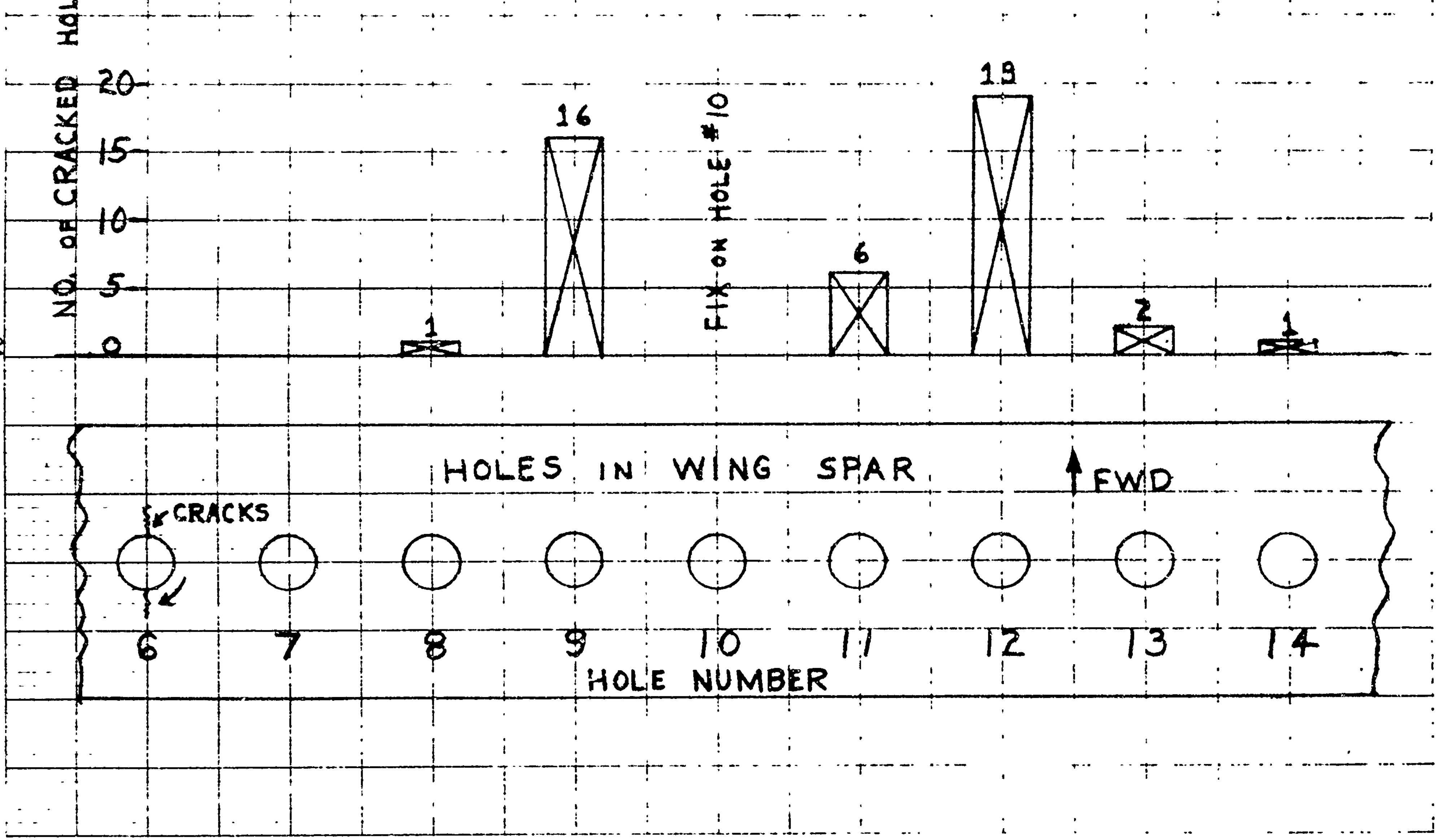
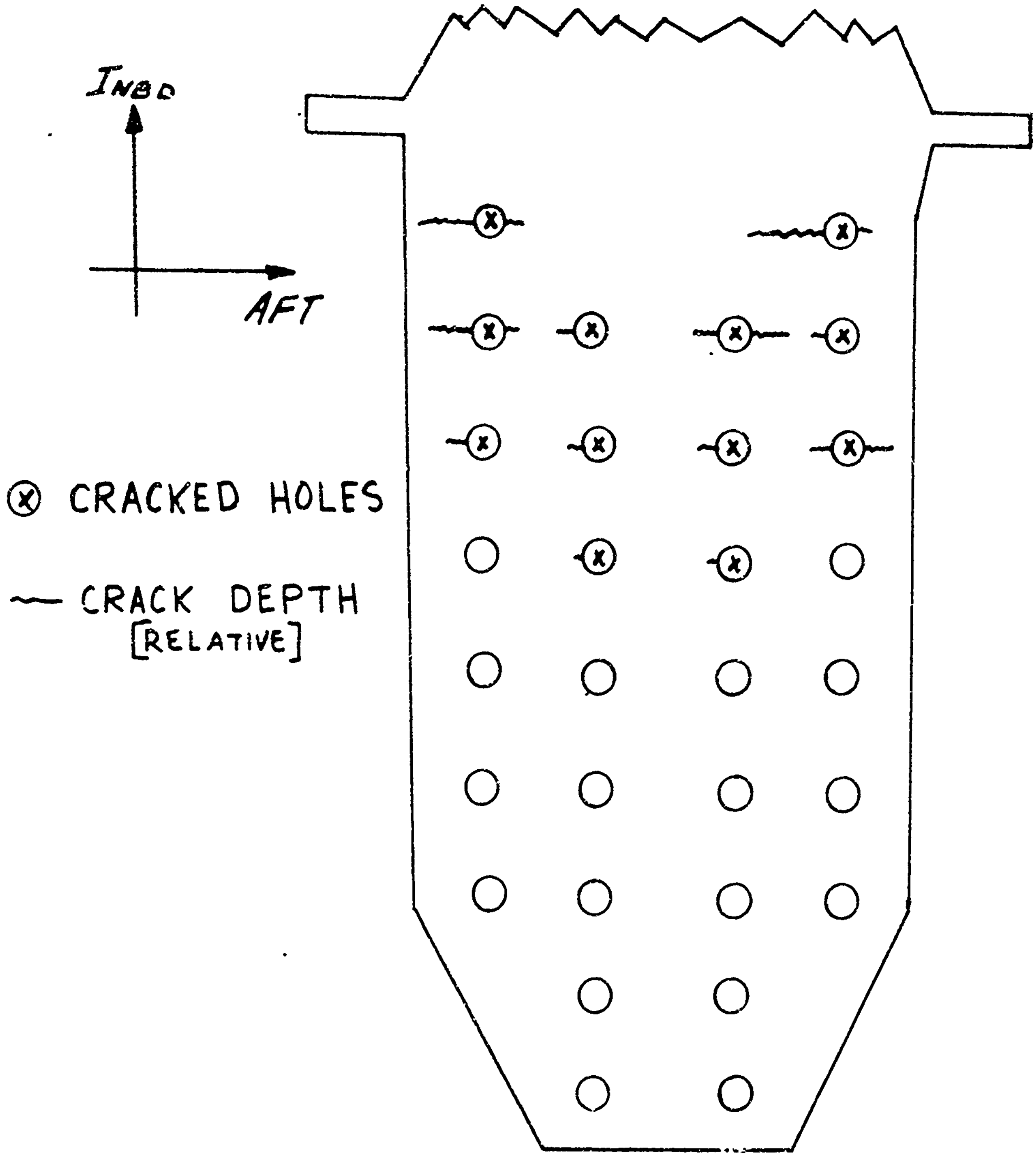


FIG 16

FREQUENCY OF HOLE CRACKS IN WING SPAR SECTION
[IDENTICAL FLIGHT TIMES] - 45 AIRCRAFT





CRACKS IN FATIGUED PART

FIG 17

FIG 18

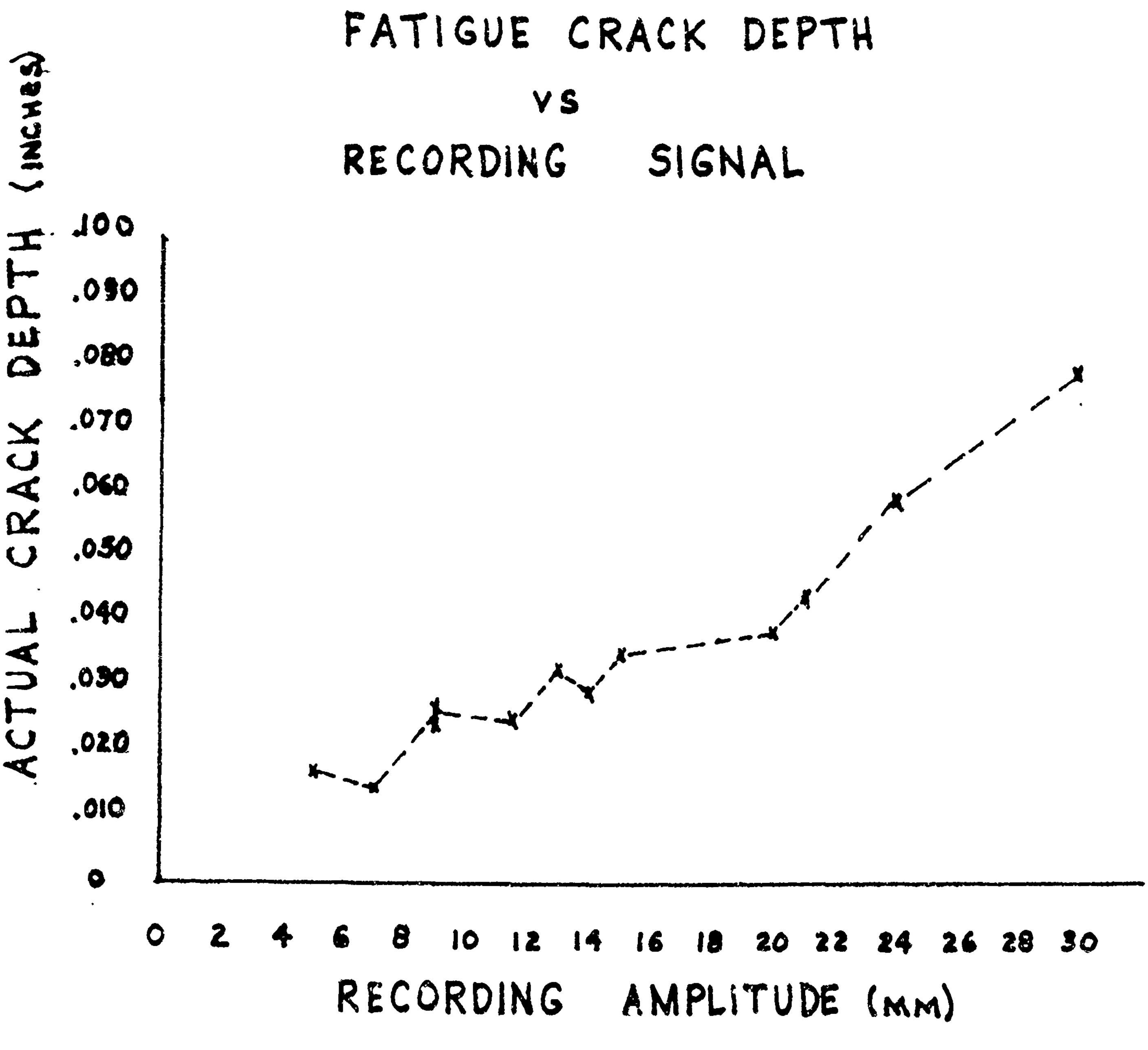
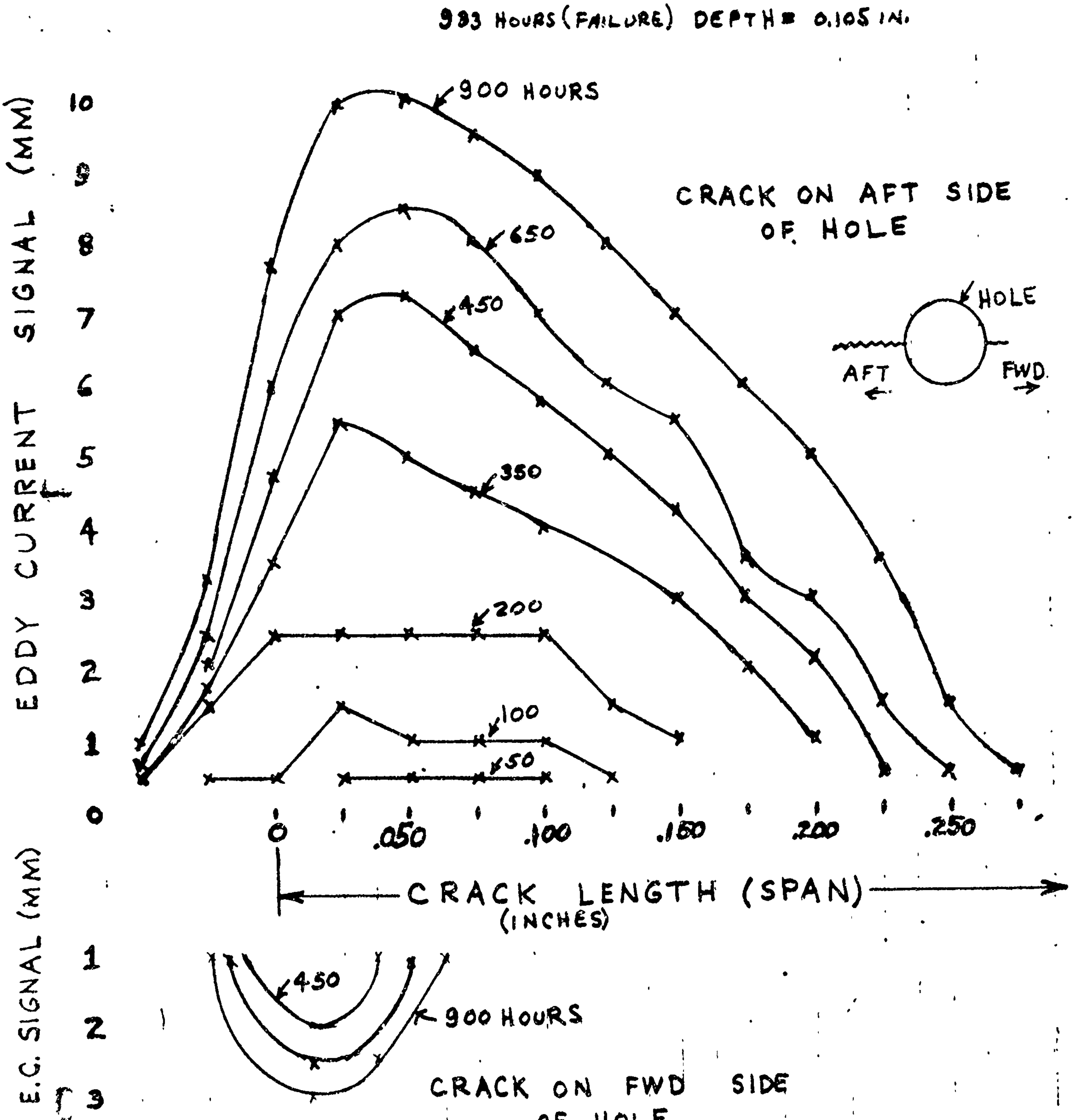

FATIGUE CRACK DEPTH
VS
RECORDING SIGNAL
ACTUAL CRACK DEPTH (INCHES)
.100
.090
.080
.070
.060
.050
.040
.030
.020
.010
0
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
RECORDING AMPLITUDE (MM)

FIG 19

CRACK PROPAGATION



PAPER #3

ABSTRACT

Semi-Automated NDT for Jet Engine Blade Inspection

A program is underway to automate a system for inspecting jet engine blades. In this inspection system, surface defects are detected by use of a fluorescent dye penetrant. The penetrant is applied in a nine-step process that includes ultrasonic cleaning of the incoming blades to remove light soils, electrostatic application of a water-washable fluorescent penetrant, and application of a developer to enhance detection of defects. Blades then proceed to the inspection station where they are scanned for residual penetrant by arrays of vidicon cameras using ultraviolet illumination. The scanned data is processed and evaluated by an on-line computer according to pre-established inspection criteria. Following inspection, accepted or rejected blades are sprayed with one of two colored dyes for identification, and the blades are ejected from the inspection station on separate discharge chutes.

Program effort is divided in three phases: Phase I covers evaluation and optimization of a fluorescent penetrant system for automatic inspection, and the construction of prototype equipment for automated penetrant application and blade inspection. Phase II covers evaluation and demonstration of the prototype semi-automatic inspection machine. This machine will demonstrate the capability to maintain a continuous inspection rate of 250 blades per hour. A two week continuous operation capability demonstration of the unit is scheduled for October at Bendix Research Center. The unit will then be shipped to Tinker AFB, Oklahoma to demonstrate operational capability for a 40 hour single shift period. The operational period at Tinker AFB will demonstrate production rate capability, reliability and performance on a per blade basis. Phase III consists of the design of a fully automated system capable of inspection rates of 500 parts per hour.

J. R. Williamson
Fabrication Branch
Manufacturing Technology Division
A F Materials Laboratory
Wright-Patterson Air Force Base, Ohio 45433

PAPER NO. 3

SEMI-AUTOMATED NDT

FOR

JET ENGINE BLADE INSPECTION

by

Lt Richard A. Dove
John R. Williamson
United States Air Force
Air Force Materials Laboratory
Manufacturing Technology Division
Wright-Patterson Air Force Base, Ohio

SUMMARY

Under contract to the Manufacturing Technology Division of the Air Force Materials Laboratory, Bendix Research Laboratories has automated a system for inspecting jet engine blades. In this system, surface defects are detected by use of a fluorescent dye penetrant. The penetrant is applied in a nine-step process that includes ultrasonic cleaning of the incoming blades to remove light soils, electrostatic application of a water-washable fluorescent penetrant, and application of a developer to enhance detection of defects. Blades then proceed to an inspection station where they are scanned for residual penetrant by arrays of vidicon cameras using ultraviolet illumination. The scanned data is processed and evaluated by an on-line computer according to pre-established inspection criteria. Following inspection, accepted or rejected blades are sprayed with one of two colored dyes for identification, and the blades are ejected from the inspection station on separate discharge chutes. The machine has the capability of maintaining a continuous inspection rate of 250 blades per hour.

JET ENGINE TURBINE BLADES are critical, highly stressed components designed with a minimum margin of safety. Modern design uses nearly all of the strength capability of available materials. Consequently, stress-raising defects must be avoided. Defects, such as cracks, not only reduce the cross-sectional area available to carry the load, but they are notorious stress raisers as well. Sharp cracks can increase stresses many-fold and are particularly harmful in the bending mode of loading experienced by blades. For these reasons, blade crack detection is of great importance to the Air Force, as well as to commercial aviation. Blade reliability must be high because human life is at stake.

In service, blades are subjected to combined stresses from centrifugal loading, thermal gradients, thermal shock, occasional mechanical shock, gas stream momentum, and other forces. Applied stresses higher than desired may arise from improper design, improper manufacture and assembly, or improper maintenance and operation. Material strength capability lower than expected may come from improper composition, residual stresses, improper forming or heat treatment, stress-raising cracks or notches, corrosion, and fatigue.

In order to assure reliability, each blade used in an engine assembly is inspected for defects such as cracks, pits, etc. From the viewpoint of used blades, it can be assumed that the blades were originally acceptable in composition, micro-structure, hardness, and residual stresses. Changes in these initial conditions will probably be small. Gross mechanical damage can be detected by visual inspection at overhaul, and damaged blades can be rejected. Less obvious blade damage includes pitting corrosion, thermal fatigue cracking (chiefly at leading or trailing edges), and mechanical fatigue cracking (chiefly at blade roots). Pits may be detectable on visual inspection. However, cracks are often invisible to the eye until they are emphasized by penetrant techniques.

Present inspection techniques for jet engine blades rely heavily on the use of fluorescent dye penetrant systems. In modern plants penetrant application and developing are handled by automatic batch-processing machines; however, inspection of the processed blades is still a manual operation. For a fairly large facility, this may require many operators to handle the output of one penetrant application machine. In addition to the large expense involved for inspection labor, other undesirable features of this approach are that the quality of inspection obtained is dependent upon the skill of the inspector, his state of physical or mental well-being, and the limit of his visual acuity. On the other hand, human inspectors can quickly adapt to different types of blades and can be trained to "read" the blades only in critical areas while ignoring defect indications in non-critical areas.

Automatic inspection offers advantages in speed, quality, and consistency of inspection, and has potential for reducing inspection cost by reducing the number of human inspectors required. By proper design

some of the flexibility of the human inspector can also be incorporated into an automatic inspection system.

SYSTEM OVERVIEW

Under contract to the Manufacturing Technology Division of the Air Force Materials Laboratory, Bendix Research Laboratories has automated a system for inspecting jet engine blades. A plan view of the system is shown in Figure 1. In this system, surface defects are detected by use of a fluorescent dye penetrant. The penetrant is applied in a nine-step process that includes ultrasonic cleaning of the incoming blades to remove light soils, electrostatic application of a water-washable fluorescent penetrant, and application of a developer to enhance detection of defects. Blades then proceed to an inspection station where they are scanned for residual penetrant by arrays of vidicon cameras using ultraviolet illumination. The scanned data is processed and evaluated by an on-line computer according to pre-established inspection criteria. Following inspection, accepted or rejected blades are sprayed with one of two colored dyes for identification, and the blades are ejected from the inspection station on separate discharge chutes. The machine has the capability of maintaining a continuous inspection rate of 250 blades per hour. This system was evolved by interfacing advanced technology and commercially available hardware. The major technology application involved is pattern recognition which has been successfully demonstrated on other systems. The dye penetrant process was optimized utilizing off-the-shelf chemicals and hardware. Table I summarizes the commercial availability of equipment utilized in this system. This system provides a unique combination of computer technology and existing hardware.

BLADE HANDLING SYSTEM

A conveyer of the power-and-free type is used to transport blades through the penetrant application and inspection stations. Attached to the power-and-free conveyor are a total of twenty-five blade carriers (See Figure 2) with a capacity of 10 blades each. Individual blade clamps are used to attach blades to the blade carriers.

PENETRANT PROCESSING SYSTEM

STATION 1 - ULTRASONIC CLEANER. (Figure 3) Since the Air Force overhaul center presently cleans blades before inspection, the cleaning process was not considered a part of this inspection system. However, the method of cleaning can affect the efficiency of the penetrant system. Careless handling may result in fingerprints on the cleaned parts. Also, some cleaning residues may chemically react with penetrants, dyes, or emulsifiers and degrade the system. For these reasons, an ultrasonic cleaning operation was included as the first station to remove light soils. The blades are ultrasonically agitated in a heated detergent solution.

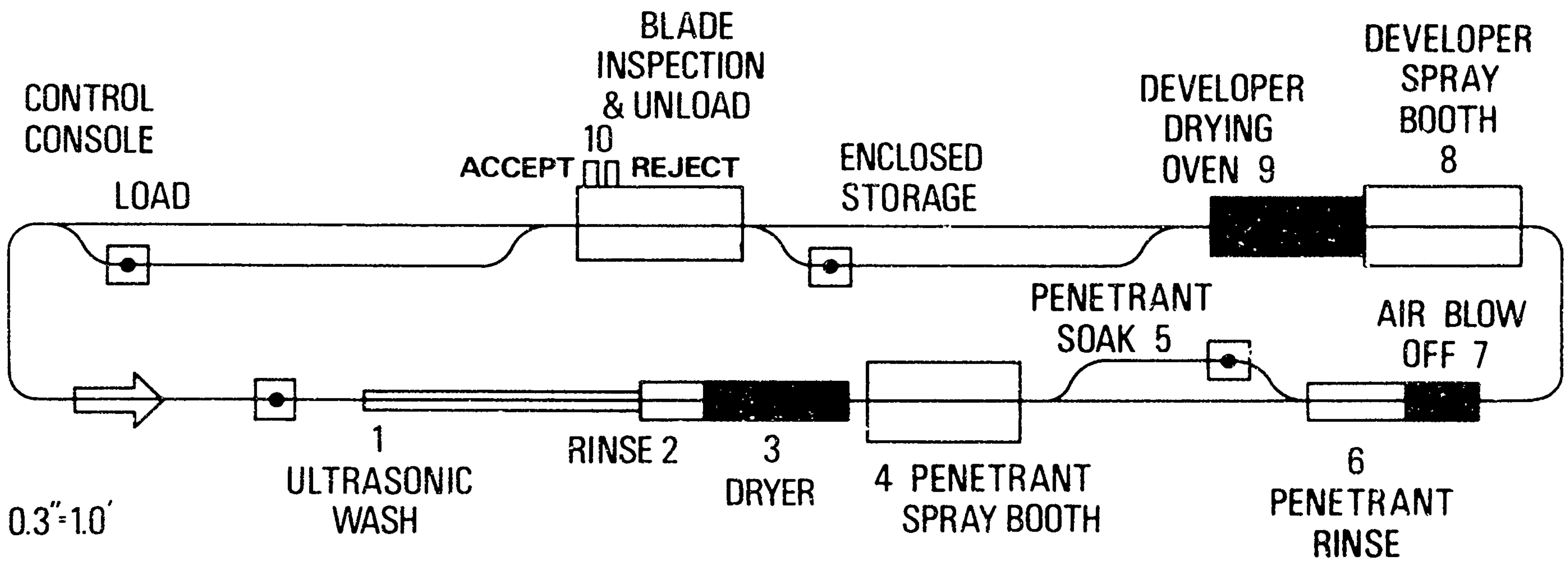


Figure 1 - System Layout

TABLE I

Station Number	Unit Operation	Type of Equipment	Manufacturer & Model No.	Operating Temperature	Time in Station
1	Clean	Sonic Cleaner	Bendix Instrument & Life Support Div. SYS-9100-WA-1	160°F	1 1/2 Min.
		Detergent	Bendix Dir-Lum Cleaner		
2	Rinse	Water Spray	Custom Made	140°F	1/2 Min.
3	Dry	Air Knife & Oven	Arthur B. Myr Sheet Metal Industries, Inc.	165°F	1 1/2 Min.
4	Apply Penetrant	Electrostatic Spray	Ransberg Electro Coating Corp. 317/13944	Ambient	1 1/2 Min. (Blades are sprayed at a rate of 24 blades per minute)
		Penetrant	Magnaflux ZL-18A		
5	Soak			Ambient	10 Min.
6	Wash	Water Spray	Custom Made	Ambient	1 Min.
7	Dry	Air Blow-Off	Custom Made	Ambient	40 Sec.
8	Develop	Electrostatic Spray	Ransberg Electro Coating Corp 317/13944	Ambient	1 1/2 Min. (Blades are sprayed at a rate of 24 blades per minute)
		Developer	Magnaflux ZP-11		
9	Dry	Forced Air Heater	Arthur B. Myr Sheet Metal Industries, Inc.	105°F	1 1/2 Min.
10	Inspect	Cameras	General Precision Labs Model 1000	Ambient	4 Min.
		Lights	Ultraviolet Products B100A		
		Blade Handling	Custom Made		

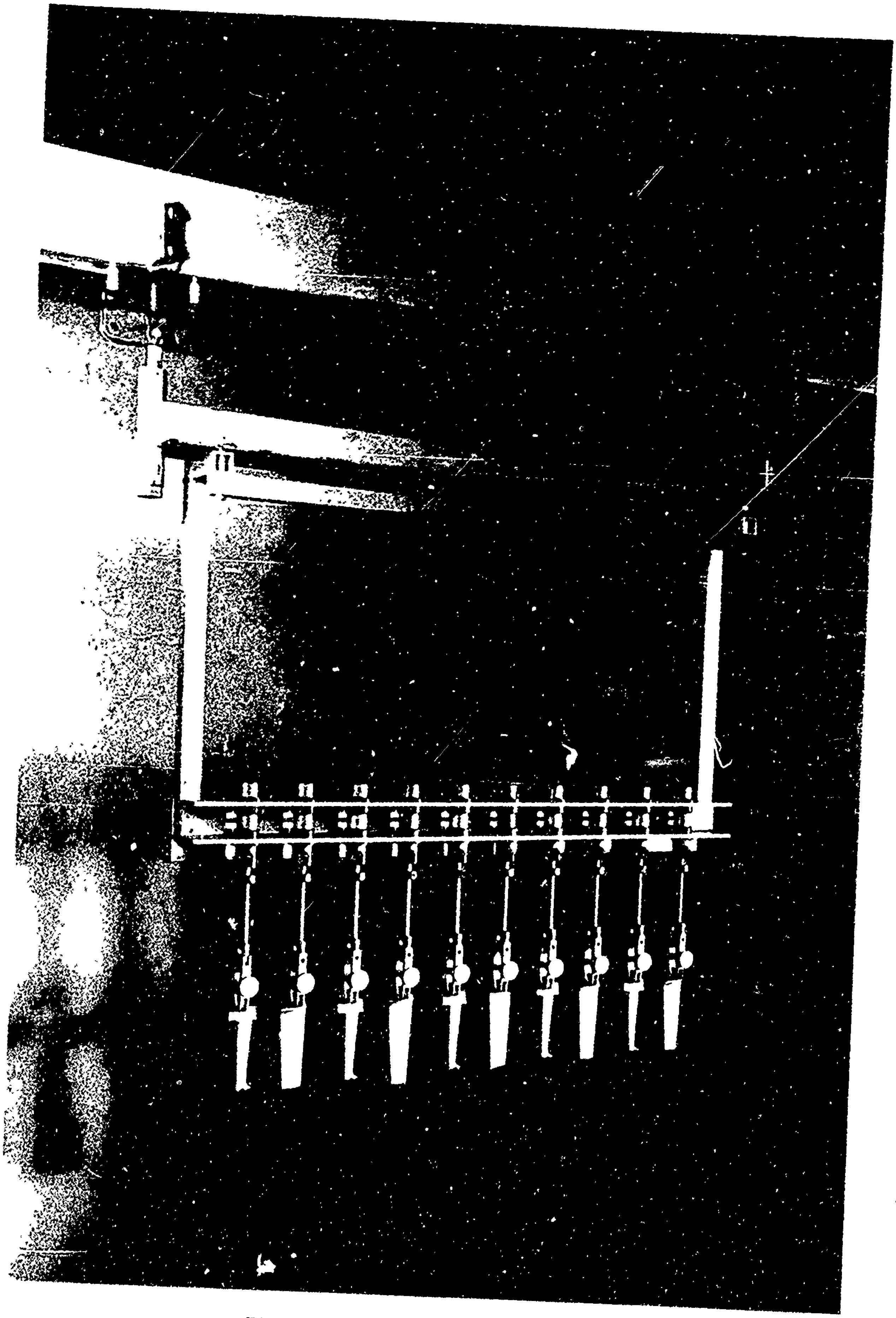


Figure 2 - Blade Carrier

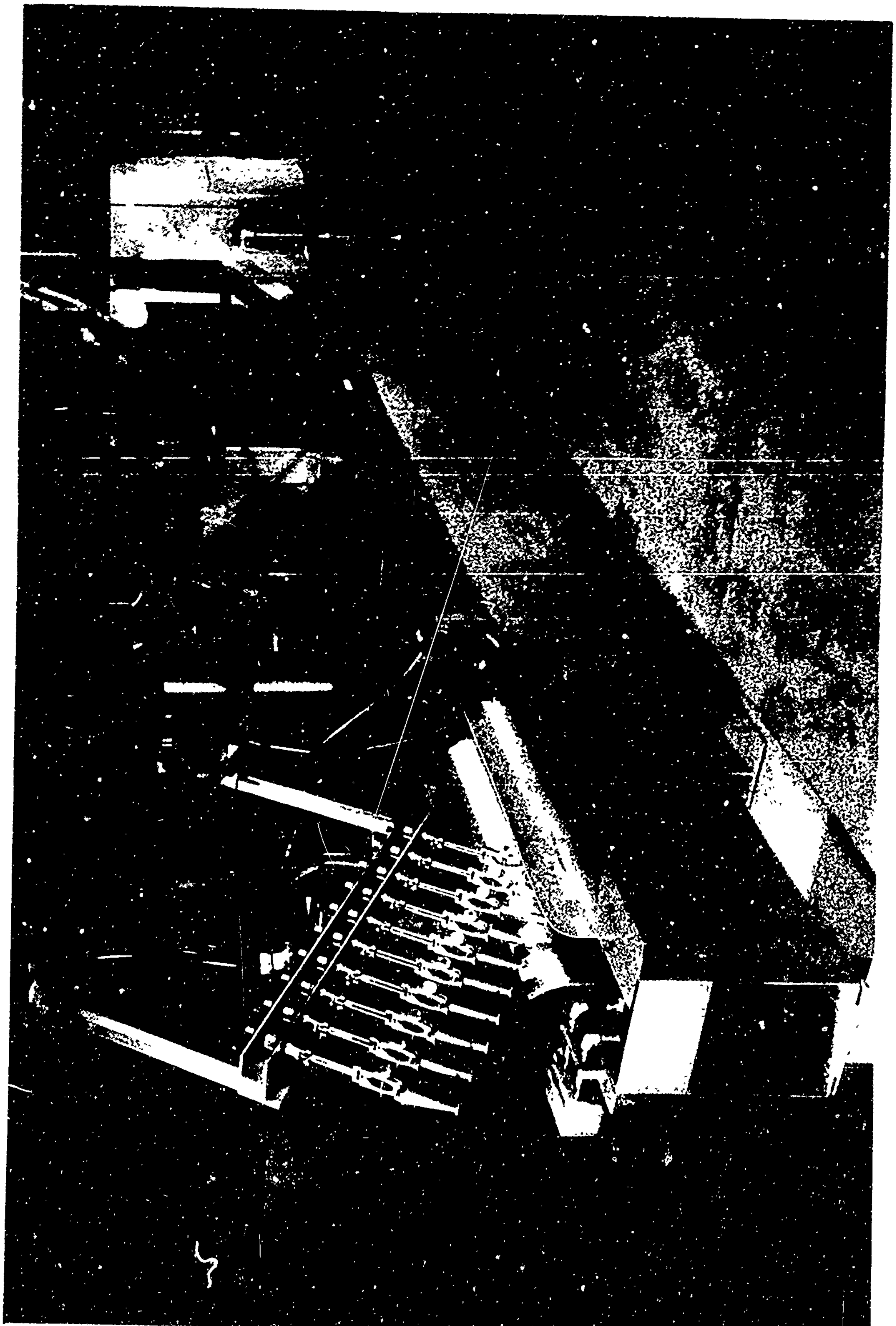


Figure 3 - Ultrasonic Cleaner & Rinse Station

STATION 2 - RINSE STATION. (Figure 3) Following the cleaning operation the blades are sprayed with warm clean water to remove all traces of the cleaner solution.

STATION 3 - HOT AIR DRYER. (Figure 4) Before the penetrant can be applied it is necessary to remove the rinse water from the smallest and tightest cracks. To do this a 9-foot long oven is used in which heated, fan-forced air is passed over the blades.

STATION 4 - PENETRANT SPRAY BOOTH. (Figure 5) A Magnaflux fluorescent penetrant (ZL-18A) is applied at the next station by electrostatic spraying. In this type of application, electrically charged atomized particles of penetrant are attracted electrostatically to the blades, which are grounded. An air type sprayer (Figure 6) atomizes the penetrant, imparts velocity, and directs the charged particles toward the blades by means of compressed air. This technique results in high efficiency of penetrant utilization and in a consistent film thickness. The present dip process used at the Oklahoma City Air Materiel Area (OCAMA) results in 10cc of penetrant per blade. Investigations in this program demonstrated that 100 percent coverage could be obtained with less than 1cc of penetrant.

STATION 5 - PENETRANT SOAK STATION. At the next station a dwell time of about 10 minutes is provided to allow the penetrant time to soak into fine cracks and other surface openings.

STATION 6 - PENETRANT RINSE STATION. (Figure 7) The penetrant inspection process requires that all of the penetrant be removed from the blade except that in the cracks and other defects. This is accomplished by using a spray rinse with a large volume of coarse water droplets. By using large water droplets the water-washable penetrant is removed from the surface thus minimizing background fluorescent indications while leaving the penetrant in cracks and other defects to produce a visible indication of the defect.

STATION 7 - AIR BLOW OFF STATION. (Figure 7) It is then necessary to remove the rinse water that might interfere with application of the developer. Excess heat would drive the penetrant from the fine cracks. Therefore, an air knife process is used to blow off the excess water. Air blow-off nozzles have been aimed so that the water is stripped from the root area at the blade holder as the blades enter the station. The water is blown down toward the foot with successive nozzles and finally removed from under the foot of the blade before leaving the station.

STATION 8 - DEVELOPER SPRAY BOOTH. (Figure 8) To enhance defect indication a developer is electrostatically sprayed onto the blades. The developer forms a porous film on the blades and acts like a blotter to draw penetrant out of the cracks. The developer is not itself fluorescent and thus acts to subdue background fluorescence on parts and cause defects to show up with a high degree of contrast. The Magnaflux devel-

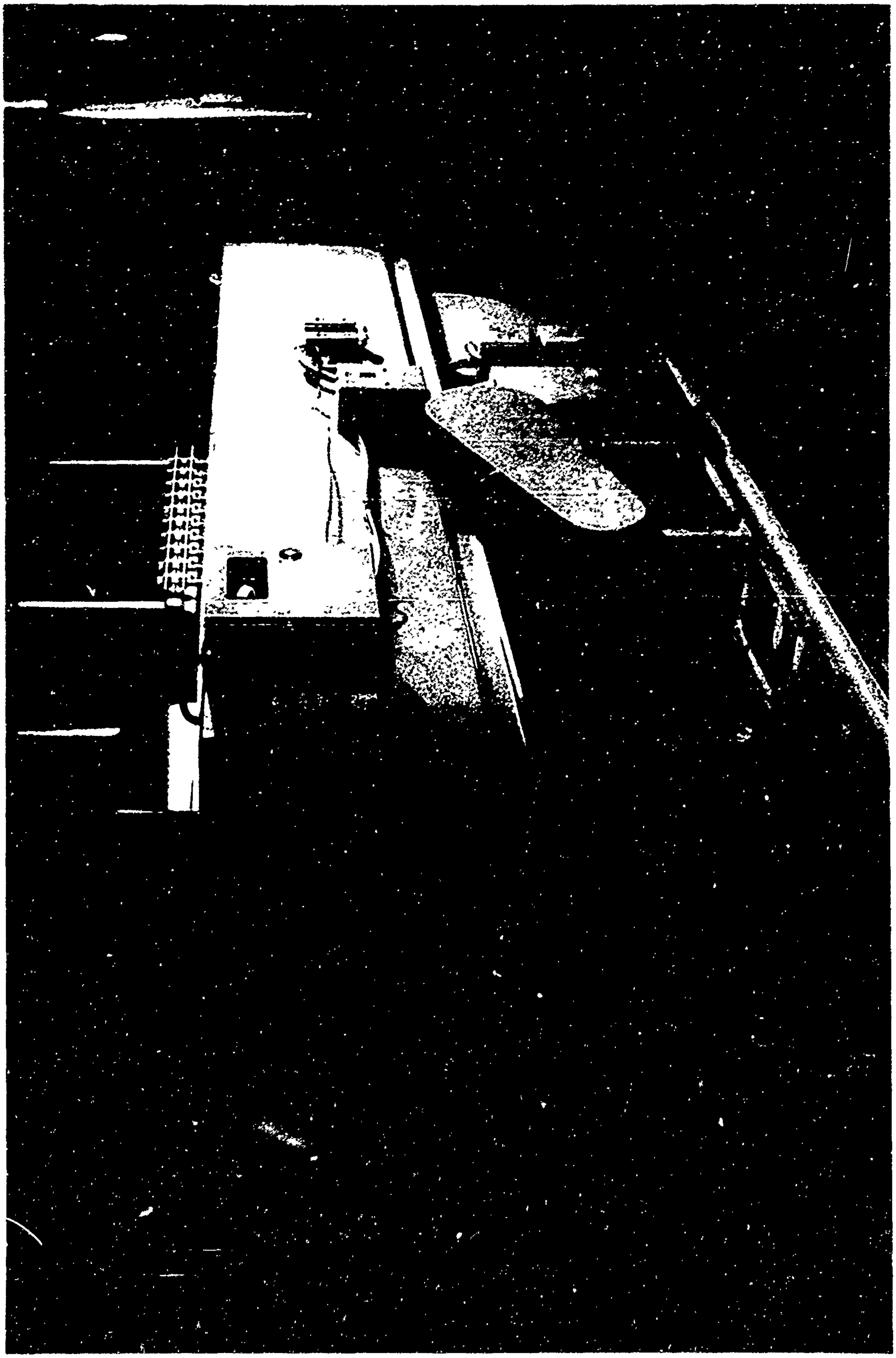


Figure 4 - Hot Air Dryer

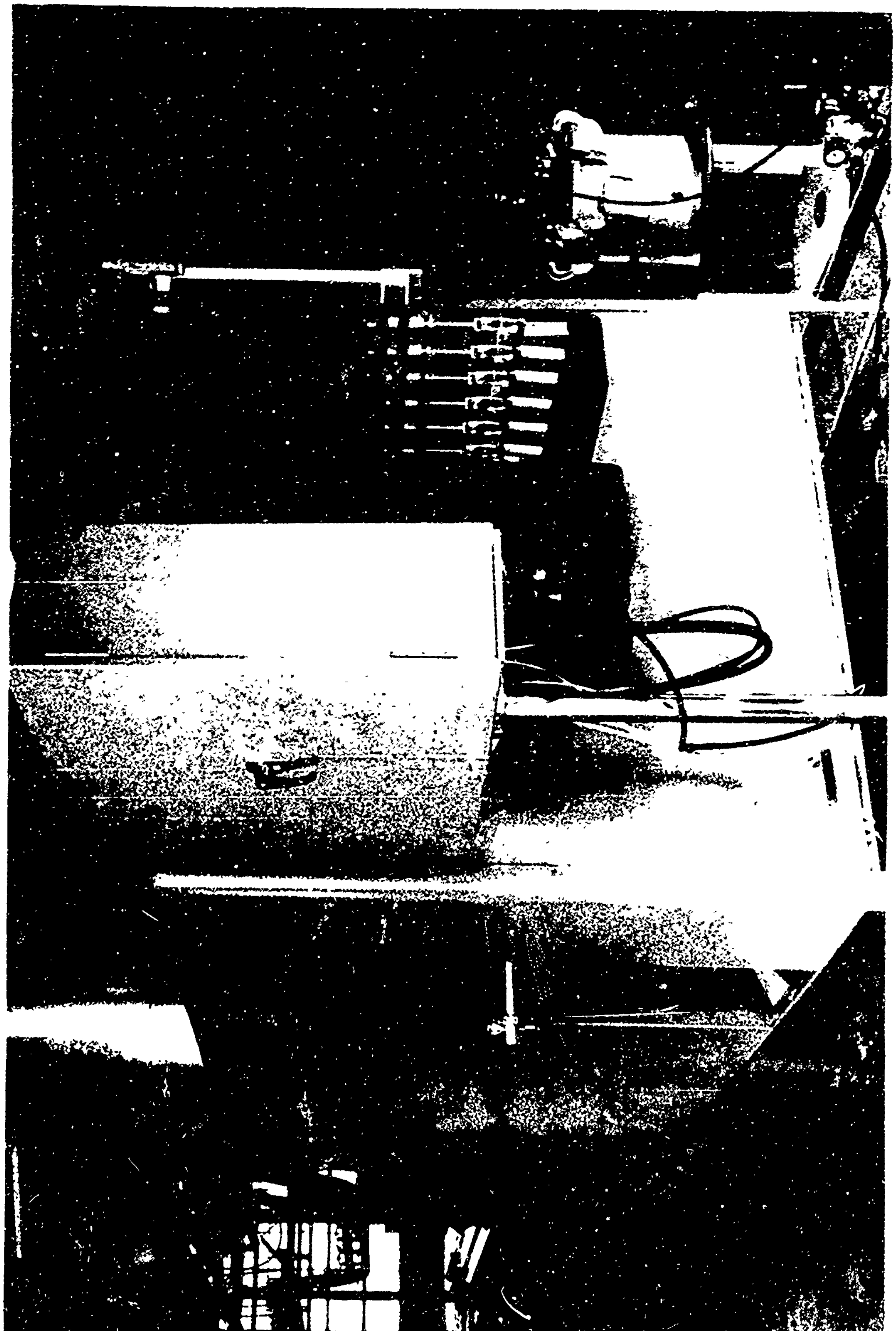


Figure 5 - Penetrant Spray Booth

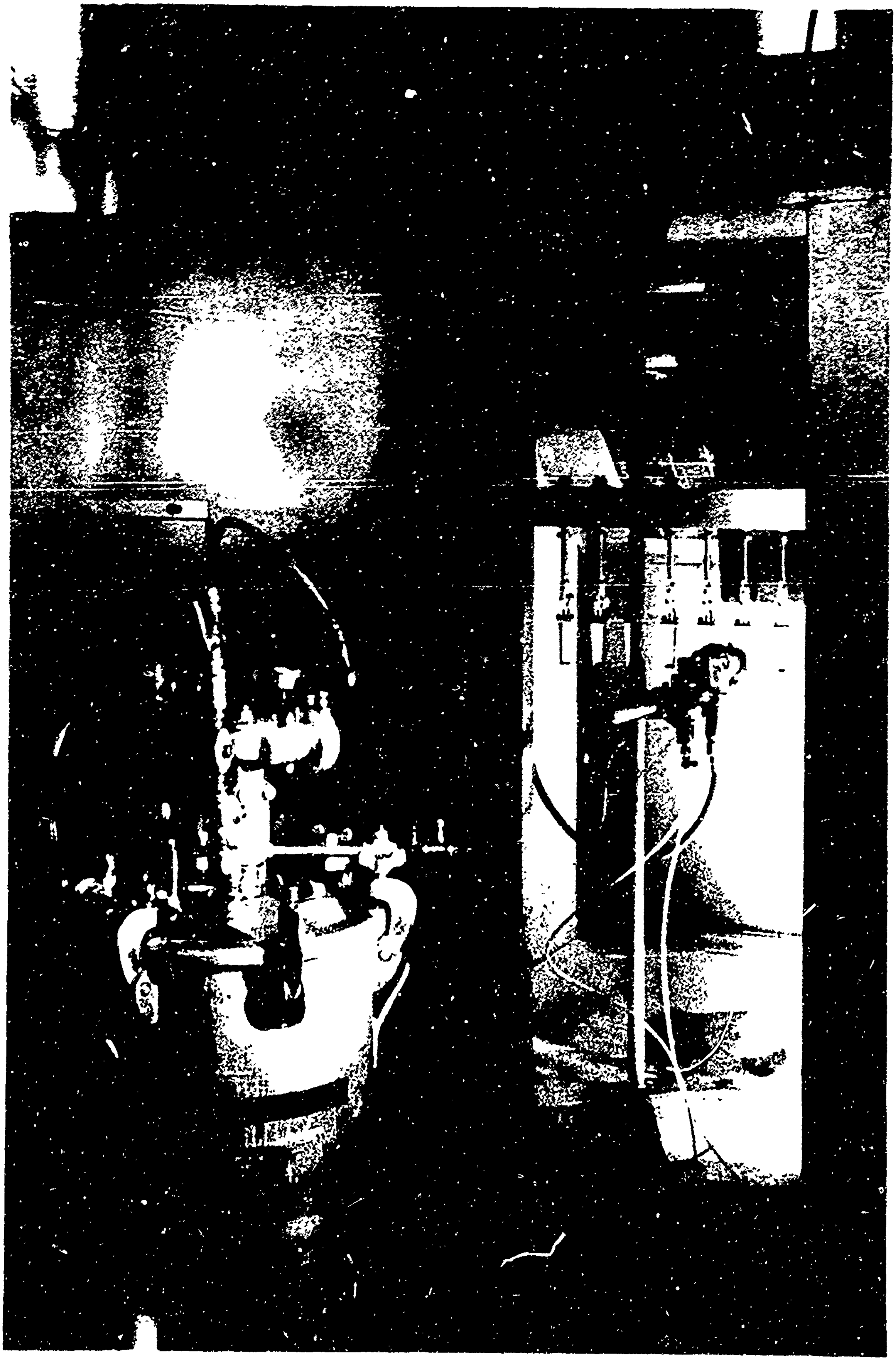


Figure 6 - Electrostatic Spray

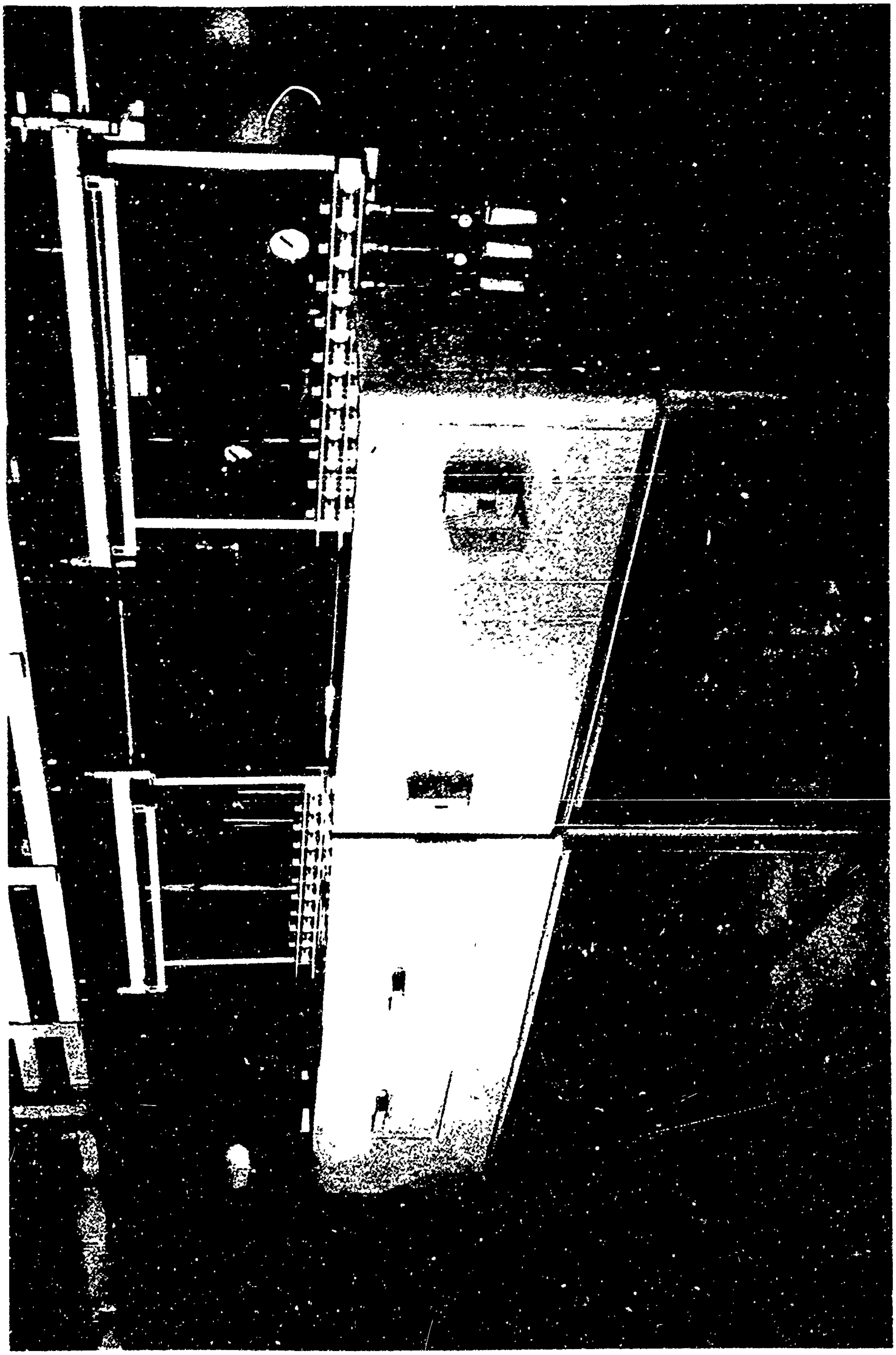


Figure 7 - Penetrant Rinse & Air Blow Off Stations

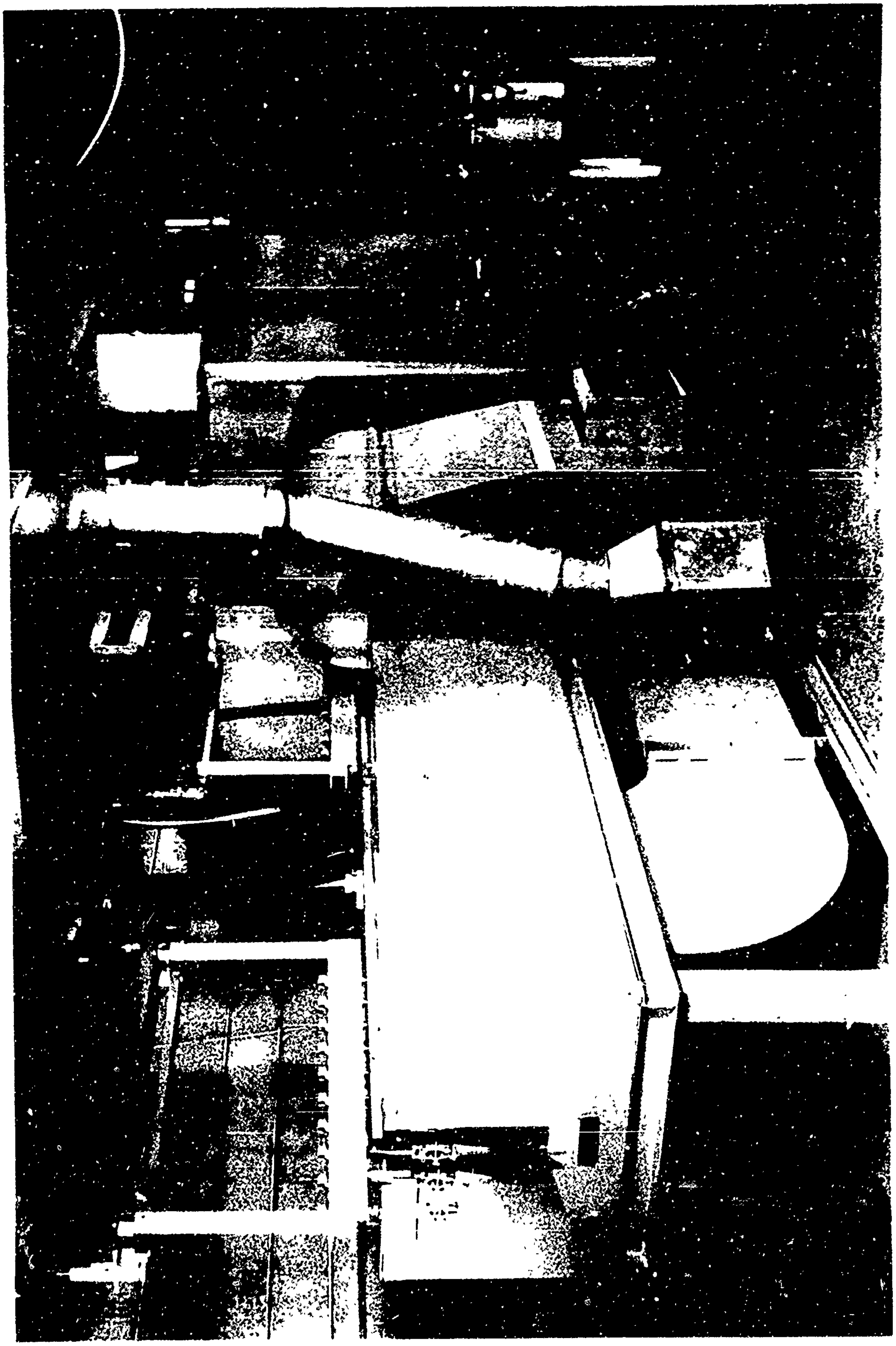


Figure 8 - Developer Spray Booth & Drying Oven

oper (ZP-11) used is a low cost, water-suspended developer that can be easily rinsed off after inspection. The developer increases the crack indication by about four-fold.

STATION 9 - DEVELOPER DRYING OVEN. (Figure 8) The developer is dried in a recirculating hot-air dryer. Since the film is very thin, short times and low temperatures can be used thus preventing excessive bleedout of penetrant.

ENCLOSED STORAGE. (Figure 9) Upon completion of the penetrant application process, prepared blades enter an enclosed diagonal storage area which has the capacity to store all 25 blade carriers in the system. The storage area acts as a buffer; if the inspection station is shut down, processing can continue in all penetrant stations.

INSPECTION SYSTEM

STATION 10 - INSPECTION STATION. (Figures 10a & 10b) Functions performed by the inspection station are vidicon scanning of the complete blade surfaces, dye marking of accepted and rejected blades, and ejection of blades from the blade carriers. Upon command of the system control electronics, the conveyor transports a carrier from the enclosed storage area to the inspection station. The blade carrier is released from the power track of the conveyor for the length of the inspection station.

Friction drive mechanisms provide linear transport of the carriers through the inspection station at a nominal rate of 1 inch per second. The blades are rotated 360 degrees in fixed increments as they are scanned by the vidicon cameras at the two scanning stations. Following the second scanning station, blades are dye marked by one of two solenoid-operated spray heads which apply different colors for accepted and rejected blades.

The last operation on blade carriers in the inspection station is ejection of the clamp/blade assemblies from one of the two discharge chutes. After all blades are ejected, the friction drives continue to drive the empty blade carrier out of the inspection station where it is picked up by the system conveyor and transported to the loading area.

OPTICAL SCANNING SYSTEM

The scanning system detects the presence of residual dye (due to flaws) on processed jet engine blades. This is accomplished with five vidicon cameras which scan the blades as they are presented by the mechanical handling system. The cameras are required to supply the data processing system with dimensional information on cracks as small as 0.0005 inch in width. To accomplish this, the cameras must have a resolution of at least 500 lines in both the horizontal and vertical direc-

Figure 9 - Enclosed Storage

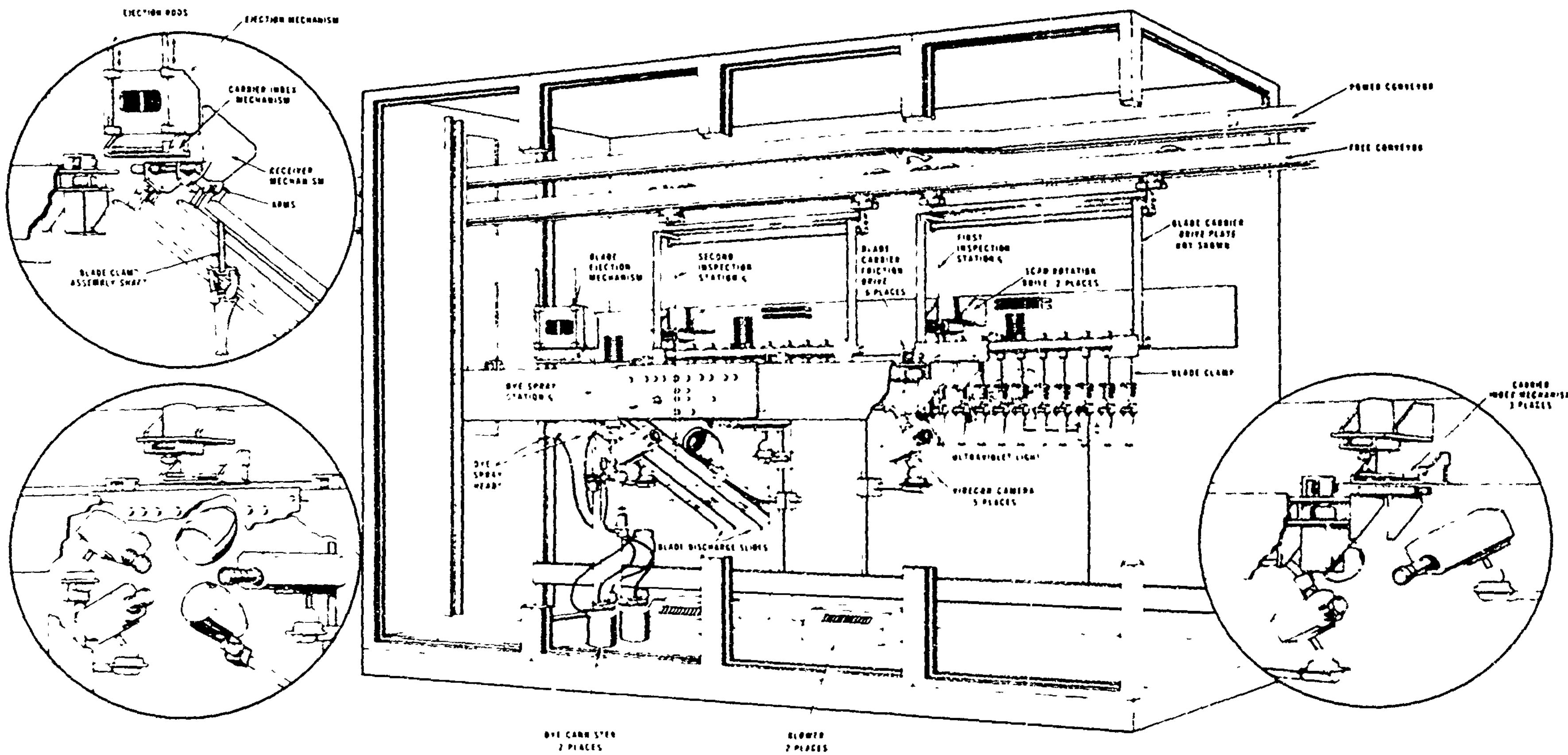


Figure 10a - Inspection Station (Line Drawing)

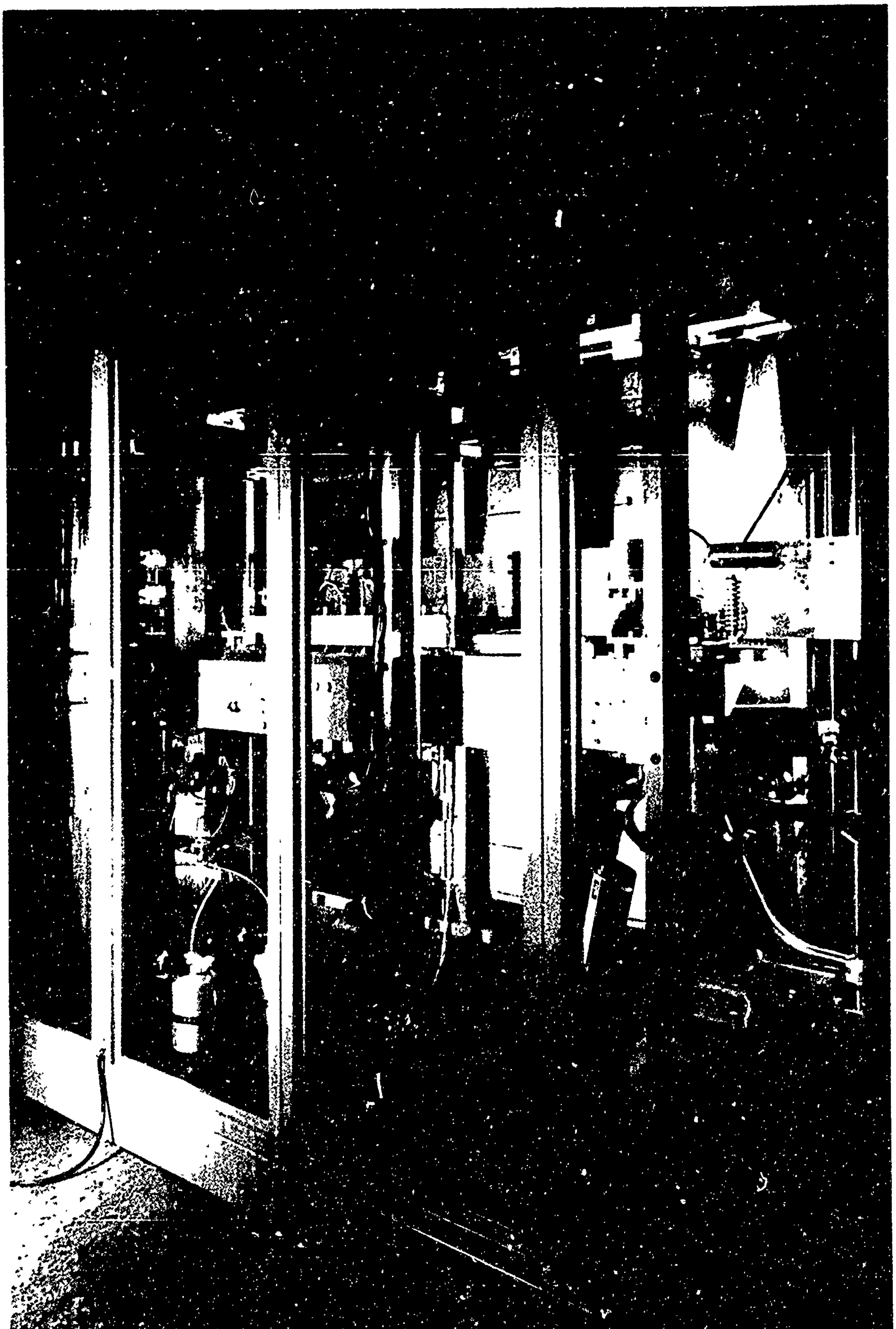


Figure 10b - Inspection Station

tions, must have a response curve that peaks in the yellow-green spectrum and attenuates the ultraviolet, and must have a minimum distortion or maximum signal-to-noise ratio. The required resolution is obtained due to the fact that a 0.0005 inch crack is magnified to 0.002 inch by the action of the penetrant and developer. For a one-inch scan area this implies a resolution of 1 inch/0.002 inch, or 500 lines. This system utilizes the GPL 1000 camera with an 8507 vidicon tube and a blue-green filter.

The airfoils of the blades are scanned by a three-camera, three-light configuration, and the extreme ends of blades are scanned by a two camera, two light configuration. At the three-camera station, the blade center is scanned by a horizontally mounted camera. This camera scans an area approximately 1 inch square around the entire blade as it is rotated in its holder. The other two cameras are angled to improve sensitivity to flaws located on corner surfaces and on the surfaces normal to blade axis. Three 100 watt ultraviolet spotlights are used to illuminate the blades.

Inspection of the ends (tree and tip areas) of the blades is accomplished at the other scanning station. Inspection of the tip area is accomplished by a camera angled 45 degrees below the horizontal; the camera inspecting the tree is mounted at only 20 degrees. The reduced angle is necessary to view into the tree area. The camera is not completely horizontal because it must be capable of inspecting the bottom areas on compressor blades.

The 360 degree rotation at each scanning substation is broken up into increments, and the blade is required to stop at each increment while the scan is accomplished; this prevents streaking of the fluorescence (blurred image) due to the finite image retention time of vidicon cameras. The three-camera station utilizes 12 fixed-incremental rotations of 30 degrees each while the two camera station utilizes four 90 degree stops.

Because the video data generated by the cameras occurs at a very high rate, it is preprocessed by a flaw detection circuit which reduces the data rate so that it is compatible with the computer input capability. The level of the video input signal, which comes from the cameras, is quantized by three high-speed comparators. To measure flaw width, the comparator output gates 10 mHz clock pulses into a counter for the duration of time that the camera scans across a flaw. The clock pulse frequency sets the minimum width flaw that can be measured, i.e. equivalent to one clock pulse.

DATA PROCESSING SYSTEM

The function of the data processing system is to monitor variable process parameters, determine from the flaw data which blades are to be rejected, and provide control signals in the proper sequence. These

functions are accomplished by the combination of hardwired logic system and a programmed minicomputer.

The data processing hardware is mounted in the electronics console shown in Figure 11. The upper left corner of the console houses the master indicator panel. Below this panel are the three logic drawers which constitute the computer interface. Below the logic drawers are the five camera controllers, the sync generator, and the switches that connect the camera outputs to the monitor. The process control teletype is mounted below the TV monitor. The BASIC teletype is located in a separate console. The computer is directly below the process teletype. Below the computer are the system relays and dc power supplies. For illustration, in Figure 12 the camera monitor is shown displaying an edge defect.

The design of the data processing equipment involved selecting those functions best done by computer and those best done by the logic interface, which may be considered as a hardware extension of the computer. Although there are 16K 8-bit bytes of core storage available on the Microsystems, Micro 810 Computer, only 4 K of this is available for the process control and high speed processing. The BASIC, teletype operating system (TOS), and other selected options use the other 12K of core. The high data rates generated by the vidicon cameras require that the data enter the computer via the direct memory access (DMA) channel. This implies that the interfacing logic must successively select cameras, buffer the flaw data and control the transfer of data. The computer is then commissioned to process the data as it becomes available.

The software system was designed to accommodate both the slow but easily used BASIC software for statistical evaluation and the high speed assembler language software for process control. This means that the background compiler and the programs likely to be altered by the user will be designed for using BASIC, the conversational language. The other programs, essential to the system operation and hence not likely to be altered, will be written in assembly language to conserve computer processing time.

The BASIC programs include record-keeping, setup, and decision-making. The record-keeping retains the flaw data on each blade as it passes through the various stations of the inspection system. An example is the storing of locations on blades where flaws are most prevalent. This information could be outputted at periodic intervals and may serve as useful information in blade design improvement. The setup programs provide for checking the major power supplies, the monitored parameters of the penetrant application system and the mechanical status of the inspection system. Finally, the decision-making programs provide for accept-reject decisions based on stored threshold values.

Vidicon cameras supply flaw data at a rate of 0.4 μsec/flaw. This information is buffered by the logic and supplied to the computer at a rate of a flaw every 6.6 microseconds. This flaw information goes

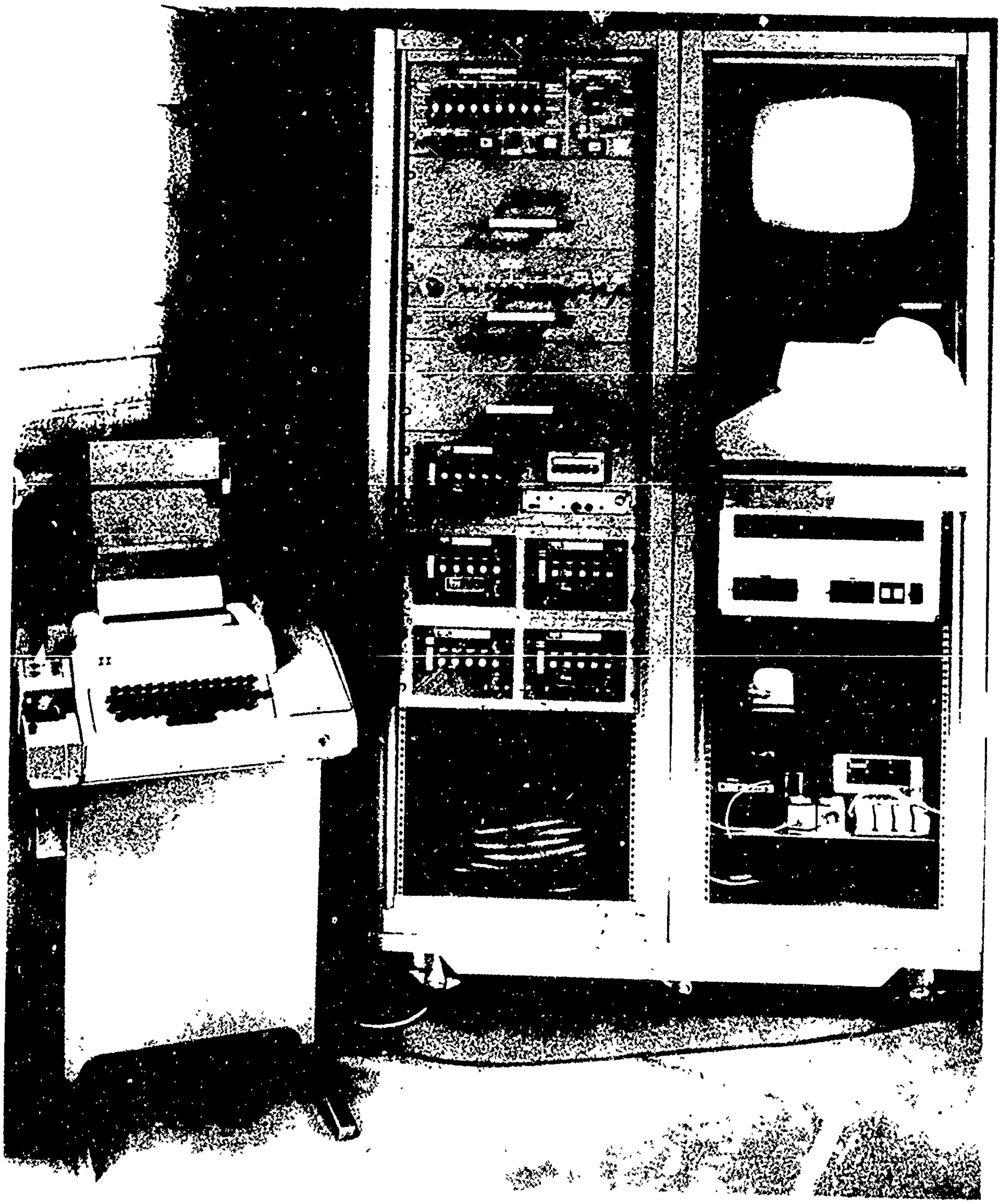


Figure 11 - Electronics Console

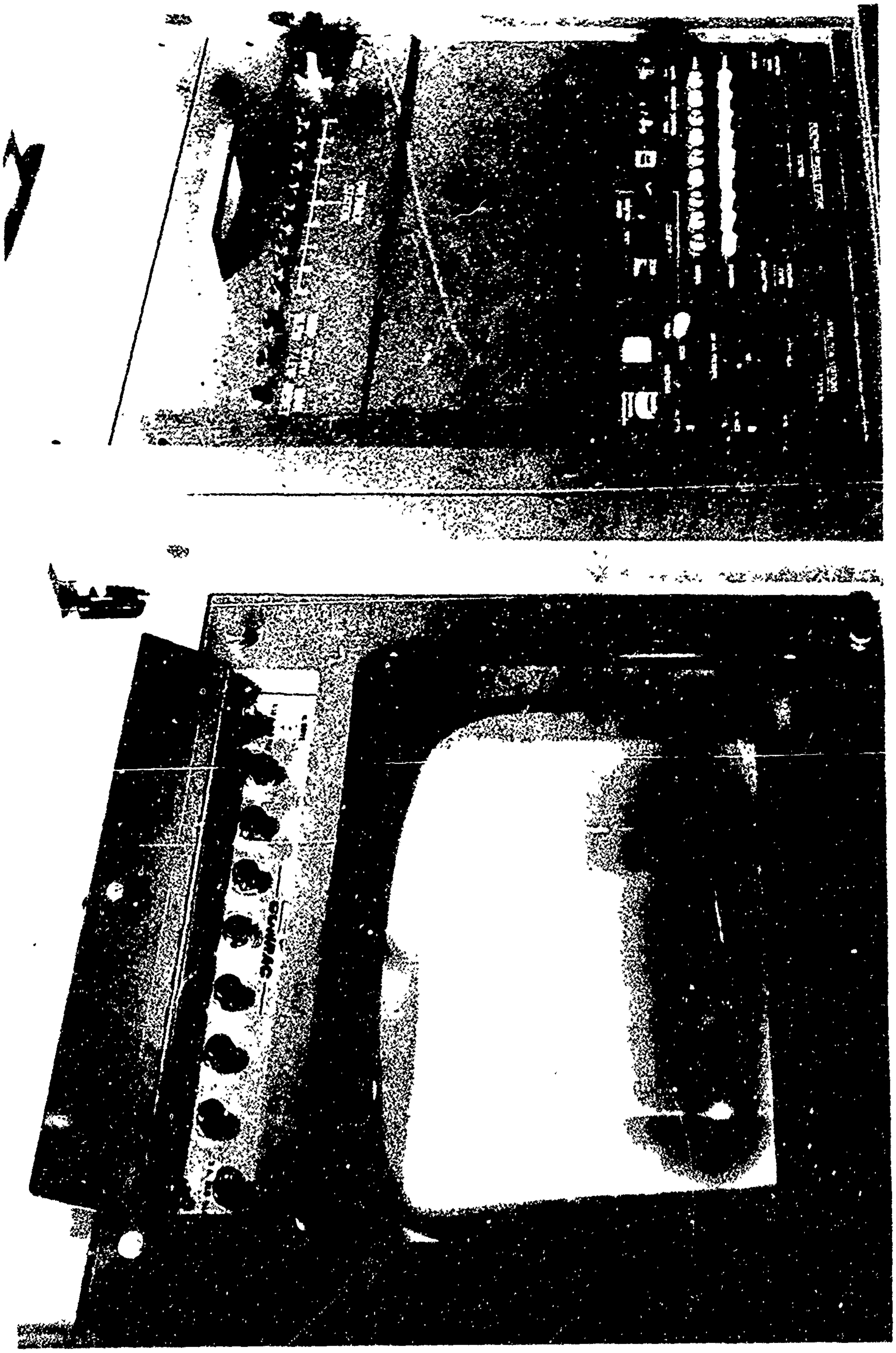


Figure 12 - TV Monitor

directly into the computer memory via the DMA channel. The processor then links the flaw information, mades a GO/NO-GO decision on each blade, and passes the processed flaw data to the BASIC processor for long-term statistical evaluation.

One of the key tasks in the decision-making process is the linking of flaw segments. This process helps to distinguish noise, or extraneous flaw signals, from signals due to finite-area flaws. The DMA is an interruptdevice. It is initially enabled, and waits for an interrupt to occur. As the camera scans across the surface, the first scan line that enters the left edge of a flaw causes an interrupt signal. The computer then monitors the video signal from that scanner and determines the position of the right edge of the flaw and the width of the flaw for that scan line. If flaw signals are detected on succeeding horizontal scan lines and if they have a similar X position, then the flaws are linked as a continuation of the flaw segment detected on the previous scan. When the end of the flaw has been detected, the flaw width for each scan line is totaled to provide an area measurement. This area is then subtracted from a threshold and if the result is positive the blade is a reject. There are two modes to the operation. The first mode stops processing after a reject is detected. The second mode continues processing even though a reject was detected. The blade will be rejected if the area of one flaw is above a certain threshold or the sums of all flaw areas are above another threshold.

CONCLUSION

This blade inspection system is currently undergoing preliminary test runs and evaluation. Several hundred blades have been automatically processed through the system. In the early evaluation tests, the system was shown to separate good and defective blades, thereby developing confidence that the penetrant process and inspection parameters were properly adjusted. The penetrant processing enhanced the defect size sufficiently to allow the inspection system to detect the defects in rejectable blades. An endurance test will be run at Bendix Research Laboratories for two weeks to prove the system's endurance and pinpoint any problems that may occur from prolonged use. The inspection results of this system will be compared to results obtained by Air Force inspectors.

Upon completion of the endurance test at Bendix, the system will be installed and demonstrated at Tinker Air Force Base. Following this, data obtained in this program will be used to provide a firm design for a fully automated production machine capable of inspecting 500 parts per hour, rather than the 250 blade per hour rate of the present system.

ACKNOWLEDGEMENT

The technical effort of this program is being conducted by Bendix Research Laboratories, Southfield, Michigan, under Air Force Contract F33615-70-C-1543. The work is being directed by R.W. Rothfusz, Manager, Control and Data-Handling Systems Department. The other principal investigators are Messrs R. S. Kiwak, M. C. Kurko, and D.J. Nadon. The authors would like to acknowledge with appreciation the assistance on this paper of Messrs R. W. Rothfusz and D. J. Nadon.

LT RICHARD A. DOVE/JOHN R. WILLIAMSON
Air Force Materials Laboratory
Manufacturing Technology Division
Wright-Patterson Air Force Base, Ohio 45433

PAPER NO. 4

DETERMINATION OF OIL DEGRADATION USING DIFFERENTIAL INFRARED SPECTROSCOPY

Raymond J. McGowan
Office of Engineering
Defense Contract Administrative Services
Van Nuys District
8900 De Soto Avenue
Canoga Park, California 91304

ABSTRACT

A technique for a rapid and accurate nondestructive determination of oil deterioration and additive depletion in petroleum base lubricants. This technique is based on the infrared absorbance measurements using differential analytical techniques. With this new technique it is possible to determine the amount of oxidation, nitration, sulfate concentration in an oil sample accurately in fifteen minutes; as compared with "wet" chemistry methods which require several days for these determinations. The application of differential infrared spectroscopy makes it possible to correct engine malfunctions and predict the service life of the lubricant.

1. INTRODUCTION

It has been apparent for several years that in most instances the present test methods for determining the deterioration of oil used in internal combustion engines has been inadequate. They are not capable of determining additive depletion, and are unable to discriminate between the products of oxidation and nitration, and fail to measure contaminants such as sulfates and water.

Differential Infrared Spectroscopy makes it possible to determine additive depletion, distinguish between the products of oxidation and nitration, and will measure contaminants, such as sulfates and water, in a matter of 15 minutes as compared with present methods requiring several hours.

2. PRINCIPLE

Infrared techniques utilize an infrared spectrometer (double beam) with a reference beam and a sample beam. In practice the sample (oil) to be analyzed is put in a sample holder, which is placed in the sample compartment of the spectrometer, and no sample in the reference compartment. The resultant spectrum is of an oil sample (Figure 1). Differential infrared technique is based upon the net difference between two samples. This is accomplished by using two similar samples, one in the reference compartment and the other in the sample compartment. The resultant spectrum would be of any component not common to both samples, for example, additives. In this study a sample of oil without additives was placed in the reference beam and a sample of oil with additives was placed in the sample beam. The resultant spectrum is that of the additives only, as shown in Figure 2. This technique clearly demonstrates that differential infrared analysis eliminates the spectra interference. This technique can also be used to determine the "life" of a lubricating oil by obtaining a differential infrared spectrum of a used oil as compared with an unused oil. The resultant spectrum would detect the percentage of nitrates, carbonyl, esters and oxidation products which determine the "life" of a lubricating oil.

3. EXPERIMENTAL

In order to demonstrate the applications of this technique the following experiments were conducted:

a. Determination of Additives. A known additive, containing 0.3% polyester and 0.5% thiophosphate, was added to a lubricating oil. A conventional spectrum (oil in sample beam only) was generated as shown in Figure 3. The complexity of the oil spectrum obscures the absorbance of the additive. To eliminate the oil spectrum, a differential spectrum was made, using an oil sample without additives in the reference beam and oil with additives in the sample beam; the resultant spectrum is shown in Figure 4. From this spectrum we can clearly see the absorbance of the additives without the interference of the lubricating oil. Note the polyester absorption at 1730 wavenumbers, alkyl group absorption at 1600 and 1500 wavenumbers, and the thiophate absorption at 1005 wavenumbers. Experimental results demonstrate that the percentage of absorbance is directly proportional to the concentration of the additives at their respective wavenumbers.

b. <u>Determining Oil Degradation</u>. In addition to identifying additive concentration, differential infrared analysis can be used to determine the "life" of a lubricating oil. To demonstrate this, a spectrum of a used lubricating oil (3,000 miles) was made using conventional infrared techniques, as shown in Figure 5. The complexity of the oil spectrum obscures the absorption peaks of the wear proaucts, such as nitrates, carboxylic acids, etc.

A differential infrared spectrum was generated using a sample of unused oil in the reference beam, and the used oil in the sample beam. The resultant spectrum is shown in Figure 6. One of the most significant features of this spectrum is the "negative" absorption at 1470 wavenumbers which is due to the fact that the additives in the used oil have become depleted. This negative absorption is due to the higher concentration of additives in the unused oil (in the reference beam) and a lower concentration of additives in the used oil in the sample beam. The principle additive that has become depleted is the polyester viscosity index improver, which is also demonstrated by a reduction in absorbance at 1730 wavenumbers. This spectrum also shows the accumulation of various wear by-products of the used oil. For example, the nitrate absorption at 1630 and 1285 wavenumbers, carboxylic acids at 1710 wavenumbers, and nitrates at 1630 wavenumbers indicate the oil is depleted and the absorption at 790 wavenumbers is caused by gasoline contamination in the oil.

4. RESULTS

The results of these experiments clearly demonstrate that differential infrared spectroscopy is an excellent technique for determining additive depletion and the degration of lubricating oils.

5. DISCUSSION

This technique also has an economical significance in view of the fact that it can be employed to determine exactly when an oil should be changed and when additives should be added, which would reduce the cost of unnecessary oil changes and/or adding additives.

It can also be employed in a preventive maintenance program to reduce repair cost of engines through a program of periodic differential infrared oil analysis.

6. ILLUSTRATIONS

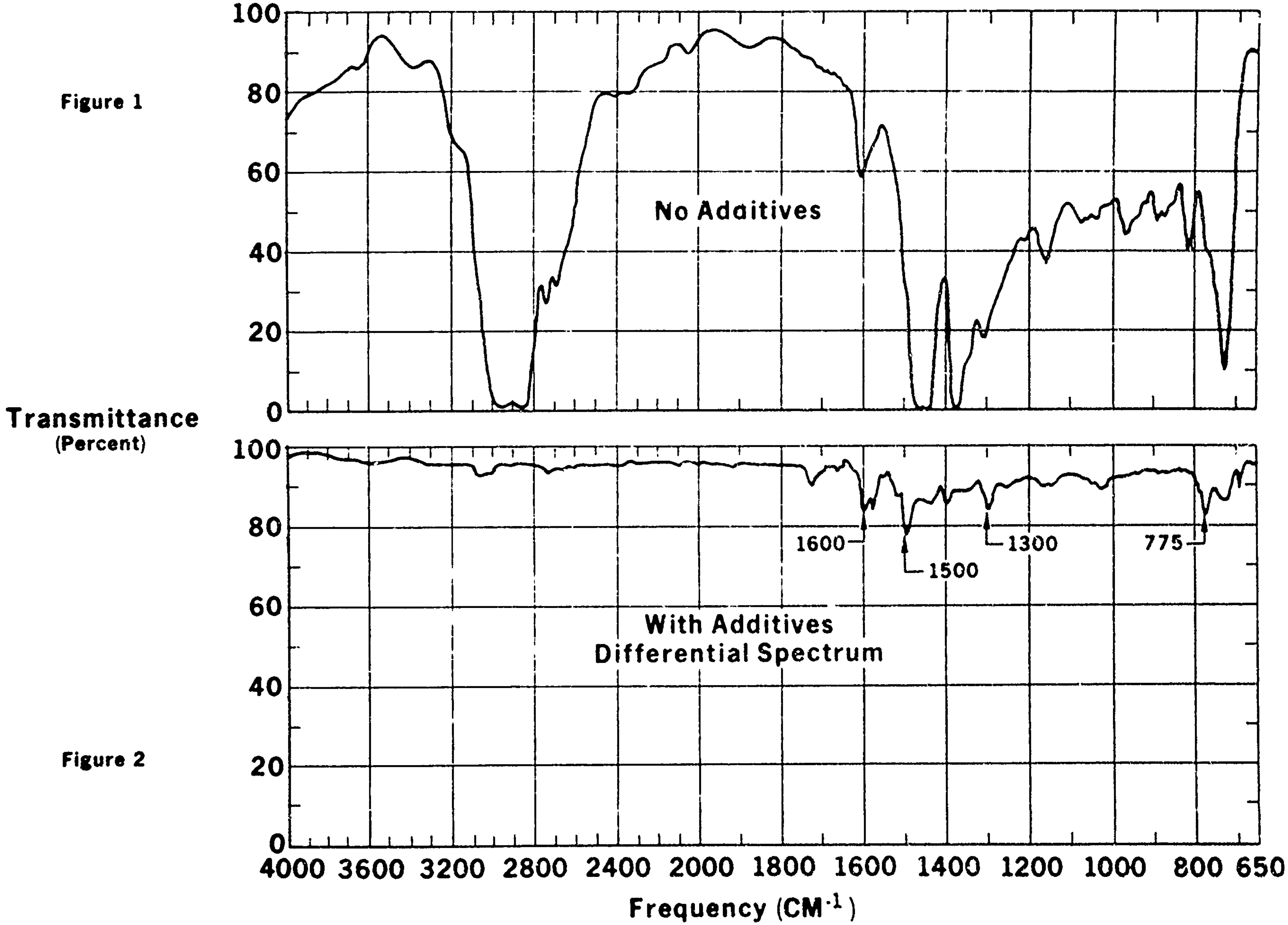
Figure 1 - Spectrum of Lubricating Oil
Figure 2 - Differential Spectrum of Lubricating Oil
Figure 3 - Spectrum of Lubricating Oil With Additives
Figure 4 - Differential Spectrum of Lubricating Oil with Additives
Figure 5 - Spectrum of Used Lubricating Oil
Figure 6 - Differential Spectrum of Used Lubricating Oil

Raymond J. McGowan
Defense Contract Administrative Services
Van Nuys District
Canoga Park, California 91304

LUBRICATING OIL

Figure 1

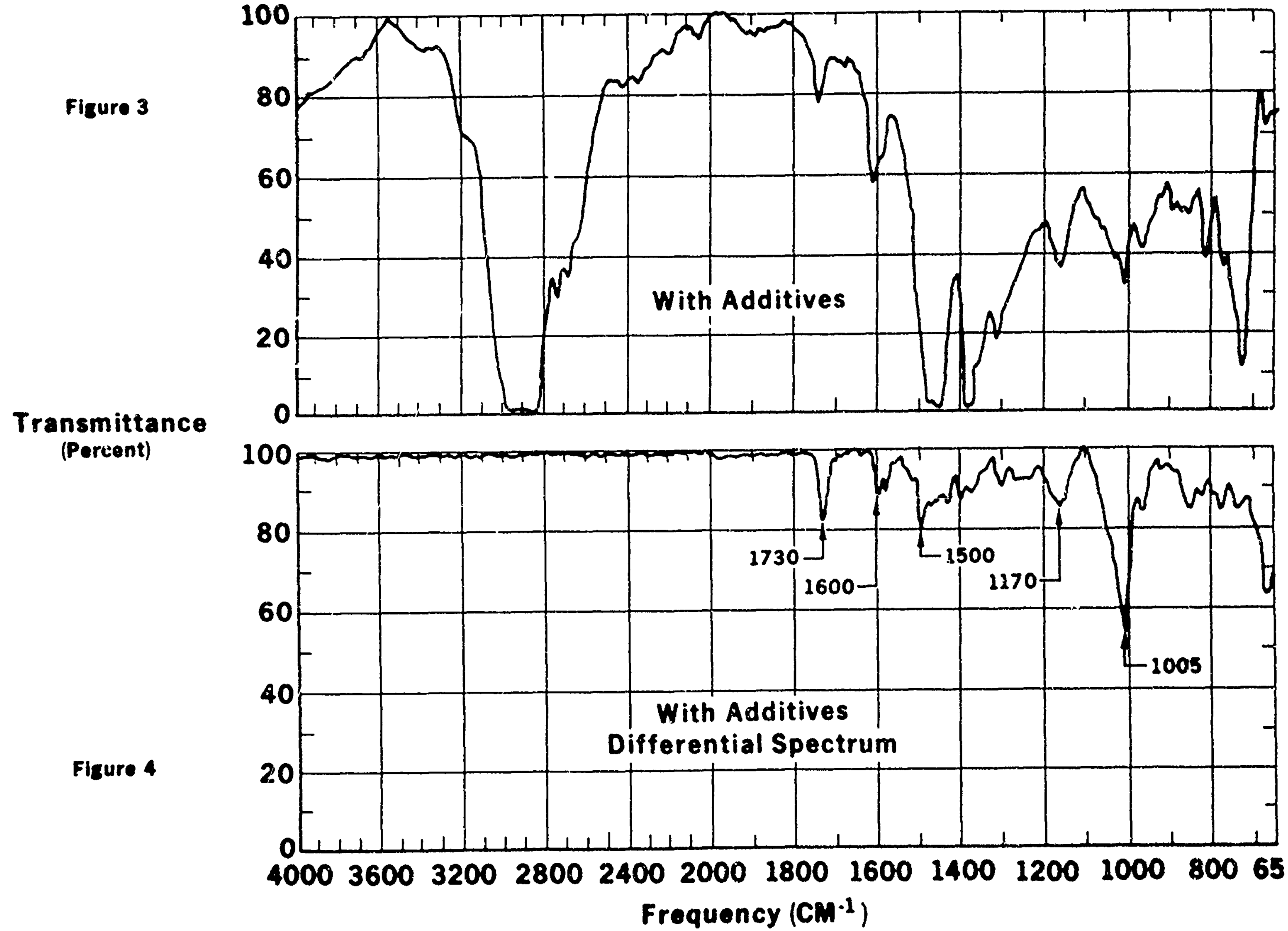
Figure 2



LUBRICATING OIL

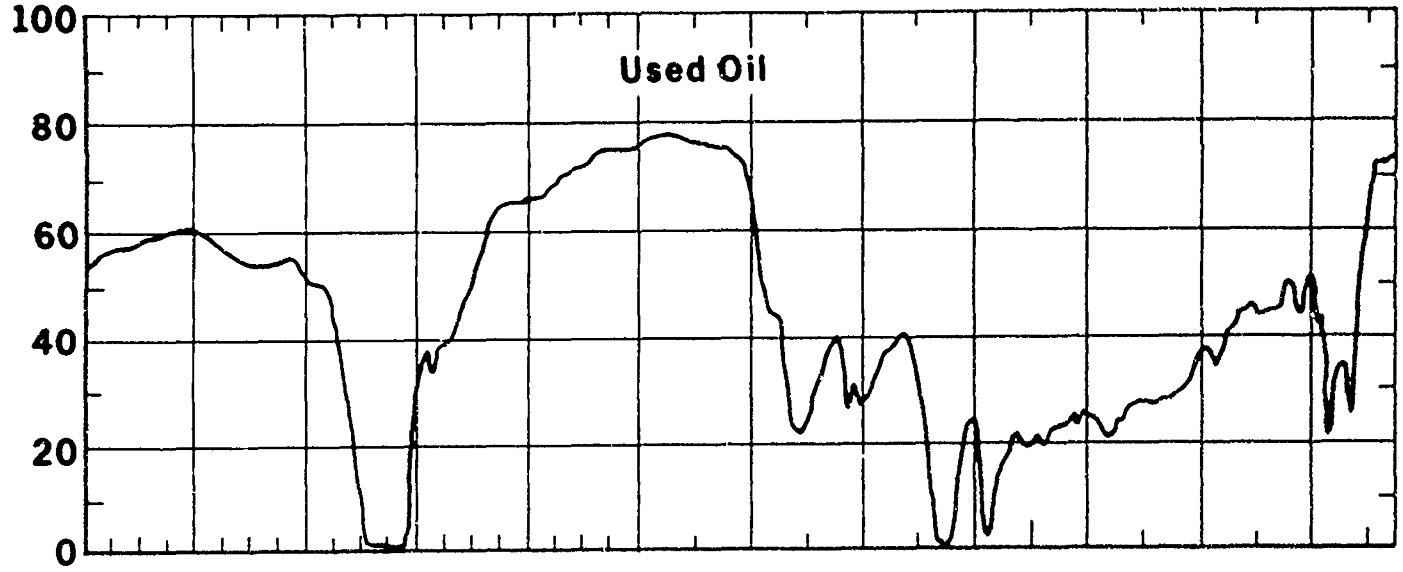
Figure 3

Figure 4



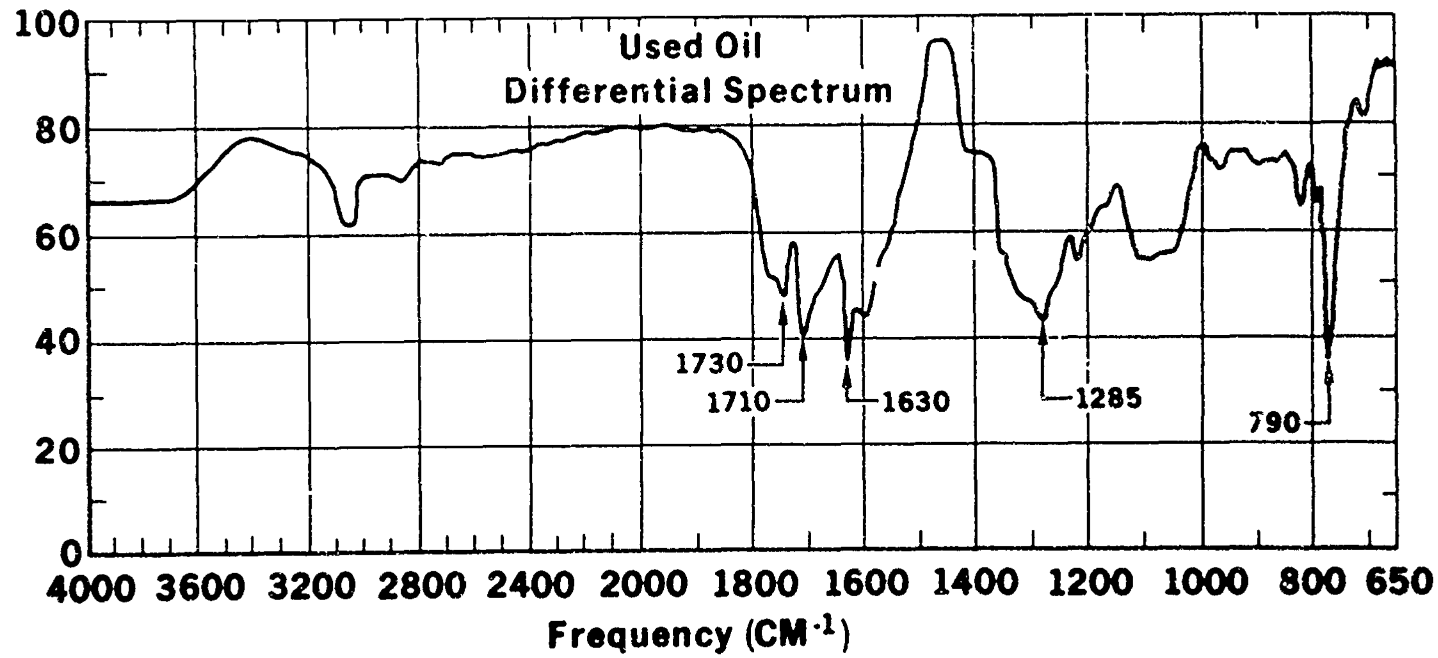
LUBRICATING OIL

Figure 5



Transmittance
(Percent)

Figure 6



PAPER #5

THE ROLE OF THE COMPUTER IN NONDESTRUCTIVE TESTING

R. J. BRACHMAN

U. S. ARMY, FRANKFORD ARSENAL

ABSTRACT

The paper presents a wide variety of applications of the mini-computer in nondestructive testing. The examples vary from simple data logging and display to complete control of test, data analysis and report presentation.

A significant portion of this paper will deal with the problems of NDT personnel purchasing and using mini-computers in their test requirements. It will cover computer characteristics as related to the NDT requirement and the potential software trap. The overall theme will be the use of the mini-computer as though it were an electronic component to be used in the instrumentation and test requirements. NDT tasks requiring as little as 100 hours data taking and data reduction will be shown to be more cost effective using the mini-computer. The paper will use illustrations of various systems using mini-computers to highlight the points under discussion.

PAPER NO. 5

THE ROLE OF THE COMPUTER IN NON-DESTRUCTIVE TESTING

R.J. BRACHMAN, U.S. ARMY FRANKFORD ARSENAL

The advent of the digital computer has been described as one of the major causes of the changing society in which we live in today. It has also tauted as being the device having the most impact on the individual in the last thousand years. The advent of the mini-computer could be considered in the same aspect if we narrow the society down to the engineering or technical community. By the term mini-computer I mean a small completely self-contained digital computer having arithemetic capability and internal memory and costing under $20,000 as a single package. Photo's of several typical mini-computers which are available today are shown in Figure 1. There are hundreds of more in this class and more coming on the market all the time.

Many people in the engineering community especially dealing with mathematics and systems analysis have been associated with large scale computers. Their transition to the mini-computer is quite simple. Other engineering areas have dealt with very complex calculators and thus the transition to the mini-computer is likewise not as complicated. But what of the individual who is involved in technology area and has been doing most of the system design himself, the data reduction in a semi-automatic manner and has involved with numbers of tests and data analysis that have not been exposed to this computer influence? Is he (she) lost? Will they be displaced by younger people having computer technology background? Other similar questions comes to ones mind. The answer is not simply "No, don't worry" but also is not "Simply yes"!. If the same common sense and logic are applied to the mini-computer application as applied to establishing test procedures, designing experiments, and analyzing data, the "older" engineer or technician should not worry.

To establish the role of the mini-computer in NDT it seems appropriate to first identify or define the test function and functional block diagram of a manual or automatic measuring system is shown in figure 2. From the device, process or "whatever under test" back through these double levels to the control block. The difference between manual or automatic systems has been just a matter of speed. The control then causes the data to be presented in tabular form, graphic form, magnetic tape, or any other device suitable for manual interpretation and analysis. This is the process block and the output block combined. In a manual test set-up, each one of these functions identified in the block diagram is a separate and distinct piece of equipment, some may be several pieces of equipment but nevertheless are completely separate, operating entities.

If standard equipment can perform all these functions, what will a mini-computer do better? Why do I need a mini-computer? What will it do for me as a test engineer? These questions are best answered in an indirect manner. If we examine each upper block and the function they perform, and determine what is the reason for the constraint on these blocks, in just about every case the limitation is due to the control and process capability. We can control many functions rapidly with sequencing or multiplexing switches but we cannot process the data at the same rate. The same is true if the control is manual. In addition, many of the devices under test are constrained to meet the limitation both from the speed of control and the analytical capacity of the process function. This philosophy actually extends into the form of data taken from the device under test, the number of test points involved, and the relationship of the test points to the information being sought. Another way of addressing the same question is to ask, "What would the configuration look like if the control was infinitely fast and the process was able to handle an infinite number of variables regardless of the mathematical complexity necessary to analyze the data?" The application of the mini-computer to this measuring system isn't quite this unconstrained. It is nevertheless several orders of magnitude improvement over conventional, that is manual or semi-automatic, measuring systems where the analysis (process) is performed by people.

If the approach to a measuring or test system is taken from the control and process point forward, with full understanding of the capabilities of mini-computers and the data analysis capabilities available, there is literally no device that cannot be tested, in general, in a non-destructive mode.

Before continuing, this point should be very clear, while the mini-computer offers almost no constraints to the control and process functions and the input/output equipment associated with these devices gives complete technical freedom to the data gathering function, the mini-computer has a penalty as equally severe at the other end for improper investigation in its application to a measurement or test system. The penalty can be so severe as to almost totally negate the useful performance of the system. This potentially devastating penalty is due to an element termed "SOFTWARE." Never has the expression "Caveat Emptor" let the buyer beware, had such meaning as in the mini-computer area. The software difficulties of mini-computers are solvable and require no breakthroughs if the buyer recognizes and understands the relationship between hardware and software and more particularly software as it applies to test or measurement system.

Prior to discussing specific examples of NDT systems, the following should highlight the unique characteristics of the computer in its role of data acquisition, control and analysis (process). These are shown in figure 3 and figure 4. The computer combines both sets of characteristics

while its manual approach relates to figure 3 only. These combined functions are handled easily, very rapidly, and highly reliably.

A matrix of typical measurements and basic transducers are shown in figure 5. It also shows a relatively limitless measurement capability when using the computer. In addition, transducers of any or all combinations can be used in the test system. The computer is basically a data manipulating device. Once the information is converted to electrical data and more specifically digital, the computer does not know nor does it care about source of the data. This is illustrated in figure 6. Therefore, it can be seen that we can solve problems in many engineering disciplines by the use of the same general mathematics.

Let us look at a few examples of different testing requirements and see how the system evolves.

The upper part of figure 7 schematically shows material flowing through a process where it will receive several coats of some material and then be further processed as it moves. We are here determining the thickness of the material and the thickness of the coating to achieve a constant overall thickness of the end product. Below, we have a schematic of the computer base testing system for this process. The line shown here separating machine area from system area is generally termed "the process interface" . The information entering the control system comes from the several Beta gages which provide information relative to the thickness of both the material and the coating thickness and machine speed of the overall process from the digital tacometer which will provide the rate of data coming from the measurement devices as well as info on the coating rate. The device below the Beta gages are called "filters," they are also sometimes called signal conditioning amplifiers. They eliminate the unwanted information which may be noise or other data and provide a signal level suitable for the converter and the computer. The next block is a multiverter, 8 channel, 14 bits. The multiverter term happens to be a trade name of Ratheon Computers, however, it features an analog-to-digital converter and an electronic sequencing switch (multiplexer) that lets the device step from position to position to position. This stepping rate is several hundred times faster than the rate at which the material moves so that no information is lost during the sequencing process. The fourteen bits generally identifies the precision of the measurement to be made and the fourteen bits absolute value then implies a measurement that is good to one part in about 16,000. The center portion of the computer which has several standard peripherial devices for outputing data or entering programs or other data and in the lower portion is shown a digital to analog connecter. This would then permit plotting of the data so that a graphical plot of the actual thickness of the coating could be attained for record purposes. Several other control functions can be performed by this system although not shown. The coating could be controlled from the signals generated by the computer which analyzes the Beta gage information against prestored standards. In addition, an alarm system could

be included, if the coating thicknesses increased or decreased below a threshold. The thickness could also be identified by the chart output relating it to a position on the web. The unacceptable material could then be cut out of the web or material so that only material within tolerance would be sent out to its suppliers. All this process takes place completely unattended.

Figure 8 is an artist drawing of a Measurement Ejection Station for determining the material characteristics of brass cups being used in the manufacturer of small arms materiel. More detail on this process and the instrumentation will be covered in another paper, however, it does provide an excellent example of how the mini-computer can be applied to a mixture of measuring devices operating in a high speed system. The production rate is 1200 parts per minute. Following the illustration from left to right, we have the introduction of the material to a lead screw. Here an eddy current measurement is made to determine the hardness category of the brass. An IR type probe which has a pre-focused beam providing an analog output is used to measure the width and height of the cup. The cup then proceeds to a waying station where a high speed servo-beam scale measures the cup weight. The cup is then continually moved along the through until it reaches the wall thickness measurement station. Here you see six ultrasonic transducers in a row plus a seventh one vertically mounted. The vertically mounted transducer provides a measurement of the thickness of the top of the cup or actually base and incidentally it does use a pulse echo type ultrasonic measurement. The cup is moving along and rotated in front of an array of six transducers. At the time the cup passes the last transducer, the computer performs an analysis based on the six measurements plus a computation relating to the wall thickness variation. If the cup is within this tolerance it continues on to the end of the line, if not the computer identifies the cup by position to the control system and as it passes the eject station the cup is ejected. This takes place incidentally as a result of any of the measuring points. You see two lines of cup and measurement instrumentation. The same computer complex actually handles both of these lines plus more. Because of the nature of the system, there is a requirement for extremely high reliability in the production mode. We can provide a calibration or self-test ability to all the electronics, however, we cannot go out beyond that point, so the concept used here is that on a periodic time base, the computer will halt the standard cups from entering the system and cause special pre-calibrated radioactive cups to be introduced into the lead screw. These cups will enter into the system and be checked by the measuring devices. They will be compared against standards stored in the computer. If they do not provide a 100% agreement, the computer identifies to the maintenance personnel that a given transducer is not functioning. Since these cups are not good cups for manufacturing purposes, we do not wish to have them enter the system. Therefore, we provide a scintillation counter at the end of the line which is scanned by the computer then causes the eject station designated for these cups to be activated to remove them from the system.

A third example is shown as follows in figure 9. This is an artist sketch of Letterkenny Army Depot test cell facility for testing tank, engines, and transmissions. These are 800 HP engines and compression ignition, spark ignition and and fuel injected spark ignition types. The cell on the right is the engine test cell and the cross-drive or transmission test cell is on the left. These two cells are operated by the computer complex shown in the middle. The test cell operator has a few controls for running the test. Although the operator performs several tests, by selecting a code on the teletype, the engine is exercised thru the computer but the operator thinks he has complete control of the test. The computer performs all the tests, analyzes the data and produces a repair report or certification of performance as required. All this is done automatically. A block diagram of this installation, Depot HHDS is shown in figure 10. This block diagram is translated into operational capabilities shown in figure 11.

This is somewhat busy, however, the important fact is that during the test of the engine or engine-transmission the system makes the following kinds of measurement prior to the data analysis. Temperature measured at 25 points, pressure - 9 points, vibration - 18 points, flow - 7 points, current - 1 point, voltage - 1 point, position - 1 point, speed - 3 points,torque - 1 point, throttle position - 1 point.

A typical output of the teletype or puting device in the test cell is shown in figure 12 in the test cell and also shows the communications between the operator. The first part of the instruction requires a date entry, ask for the mode of operation, serial number of the engine, so forth. It tells the operator what to do as far as bringing information up to level speed, check points, so forth. Some of the tests performed are shown in the parenthesis. The output is shown on the right hand side in clear text with additional information relating to stock number, number of parts, etc. Clear text output is also provided to the mechanic who will repair the engine. The output going to the repair station is similar to this form.

A different format of the data is shown in figure 13.

Briefly in this one system, we have shown that the mini-computer controls a large amount of the test,process, takes 14 different kinds of data (67 data points), produces 3 different kinds of reports suitable for different applications.

Now that sufficient interest has been aroused the next question seemingly appropriate would be, "How do I get there from here?" From the hardware standpoint, the planning of a mini-computer test system is not significantly different than any other test system. Since the system complexity and cost may get out of control earlier with the mini-computer system, it is most important to define exactly what is desired from the test or measurement system. This does not have to be in any high level mathematical form but a reasonably complete block diagram that describes

the device under test, the attributes, the relationships of these to each other and what characteristics should be derived from them. Wherever possible, specify accuracy of measurements accuracy of analysis, rate of data, numbers of inputs, numbers of parameters, whether inputs are analog form or discrete forms, ranges of inputs, and all the other necessary engineering data. Are control functions required? And if so what specifically must be presented and for what purpose, graphical forms, tabular sorted listings, weighted averages, and other variations.

We now come to one of the first departures from the manual hardware systems in considering mini-computers. We will identify this in terms of a data base. This is the information that must be provided to the computer in order to perform its functions properly, this is reference data, the amount of data to be stored in the computer, the formats for outputing the data, the terminology to be used in outputing data, the number of variables to be handled at one time, how often do you need the data, and similar information of this type. While proceeding along this line, it is necessary to indicate what one might consider growth or expansion requirements. If something happened in the process, we may want more information from here or there additional sensing stations, additional formating and so forth. This is kept in reserve but it is a necessary part of the systems configuration. The next step is to translate these requirements into equipment.

The Block diagram shown in figure 14 is typical of any computer-controlled test system. The performance of each block is similar to a manual test set-up except that the data rates are higher. The new component in the system, the computer has to be examined from a "thru-put" viewpoint. By this I mean, the time to acquire the data, place it in memory or process it, return to the proper program sequence and be ready for the next data.

Other factors have to be considered also as to reliability, operating hours, environment, and so forth. If ot for the one remaining critical feature of the system all that would be left to do would be to call in several mini-computers suppliers or go through a large number of catalogues and find the combination of characteristics both functionally and price that would satisfy your needs and make up a purchase order.

We now come to the "moment of truth" in the development and use a computer control test system.

Software is often compared to an iceberg. Only 10% of requirement is visible. The potential danger lies below the surface. Figure 15 illustrates the confusion within the software environment of the computer industry. If there is such confusion between experts, what chance does a novice have? Does he have to become a programmer?. The purpose of this discussion is to show test personnel how to use computers, and not make programmers out of test personnel. However, we cannot ignore the fact that some of the terminology of programming and the general role it plays has to be understood.

There are three basic levels of language today. There are many variations of some of these levels. The three levels and a variation is shown in figure 16. The left hand column is referred to as machine language. This is the binery digits or bits that the machine recognizes and operates on. To learn this language would be an next to an impossible task andnot really solved anything. The Assembly Language changes the numbers into words but still has some of the learning problems of machine languages. FORTRAN and ALGOL come closer to English statements and are the easiest to learn. The higher level languages are also called compiliers. This isnot quite a true statement. A compiler is a program in itself which recognizes the higher level language and translates it into machine language so the mini-computer can do its thing. These are also called programming aids.

In discussing the programming aids we will only discuss those aids useable on the mini computer itself and not consider any other machine to generate mini computer programs. All mini computers have assembly language programming aids. Just about all mini computers have FORTRAN Compilers,however, there are two kinds of FORTRAN and several levels of compiling capability depending upon how much memory you buy and what peripheral devices you have with the equipment. These other elements are only for the purpose of preparing the software programs to permit the test system to operate.

Fortunately most of the mini computers manufacturers have recognized the fact that software can make or break a system and they have gone to great lengths to simplify the problems of programming the computer. One such approach was the introduction of a language called Basic (Beginners All Purpose Symbolic Instruction Code). This is a fairly simple language, follows, simple rules and is usually easy

to use. It is not a rapid method of programming however, one must trade-off simplicity for something.

Here is a simple program in BASIC that determines the average of five numbers typed in by the user:

```
100 INPUT A,B,C,D,E

200 LET X = (A+B+C+D+E)/5

300 PRINT X

400 END
```

Most uses of Basic are such that the operator types in part of the information, the compueer then repeats back on the printer in clear text what the operator is to do next and through a series of steps of this type the operator actually programs his problem. Basic is not available on all machines but a similar class of aid called an interactive assembler is usually available.

Another approach to the software problem is the one we use. However, it requires a competent programmer to set-up the procedure once set-up no knowledge of the program or computer is required. Technicians can easily use the system. The procedure contains a title and identifies the switches or buttons to be pushed. The instructions to the operator are in clear simple statements. This is shown for the Linc 8 (figure 17).

DATA COLLECT/DISPLAY/STORE

1. Mount Program Tape P1 (or P1C) on left hand unit.

2. Mount blank tape (data tape) on right hand unit.

3. Start the machine & load program DATA143 from UNIT 0

4. Set switches 2, 3 and 4 UP.

5. Press switch STAR[illegible] 20

6. The machine prints
   DATAM BN? =
   Type 375E. If you make an error type RUBOUT and repeat whole number.

7. The machine prints
   COLLECT DATA? =
   Type Y

8. The machine prints
        OUTBLK? =
      Type number of first block to store data, e.g. 10E.

9. The machine prints
        DATA? =
      Type batch number, e.g. 235E.

10. The machine prints
        RATE? =
      Type 40E

11. The machine prints
        DELAY? =
      Type 400 E

12. The machine prints numbers of sense switches which are up and asks OK? Check if sense switch 2, 3, and 4 are indeed up.

13. When operator of AMPEX tape recorder is ready
      Type Y

14. The machine prints GO and after sampling prints +1777 and displays waveform.

15. Type T to inspect second half of display. Type R to return to first half of waveform.

16. If you want to save waveform, type Y. If not go to step 19.

17. The machine prints TAG? =
       Type the serial number of record (in octal), e.g. 1E, 2E,...23E, etc.

18. The machine saves the waveform on tape (if switch 4 is up) and type CONTINUE? = If you want to stop go to step 20.

19. To collect the next record wait till operator of AMPEX tape recorder is ready and then type Y. Go to step 13.

20. If you want to reject displayed waveform, wait till operator of AMPEX tape recorder is ready and type N. Go to step 13.

21. Type N. The machine prints COLLECT DATA? -
    To continue (possibly with different parameters) type Y and proceed to step 8.
    To stop type N.

22. The machine prints EXAMINE? =
Type N

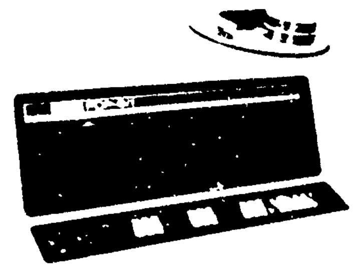
23. The machine prints RETURN TO LAP6? =
Type Y
Now the computer can be used with another program.

Now that I have all this information, what do I do with it? The procedure is relatively straight-forward, although not simple. Once the problem has been identified and the characteristics of the data known, as stated before, it is relatively straight-forward to have the computer suppliers configure from their catalogue, the hardware system to do your test program. While this is being done, you as the buyer should prepare what is commonly called a "bench mark type program". Further explore the software aids and the utilization of these softeware aids. What additional equipment is associated with these? Do not be afraid to ask for demonstration, names of people using systems, and asked, by all means contact them. Visit a local area having a computer and try to use the software aids offered. Most companies provide a training course for both programming and maintenance as part of the purchase price. However, the attendance is usually limited. Pursue the software questions until completely satisfied and if possible, until you can actually prepare a program similar in nature that you might be using in your test procedure and have the company actually run it on one of their computers. Only in this way will you be able to recognize, understand, appreciate, and treat with proper respect the software aspects of the system. Without the software you have a very beautiful, expensive and useless collection of electronics equipment.

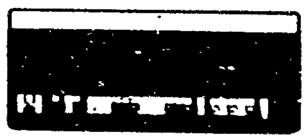
In conclusion, it should be stated that the introduction of the mini computer to the testing technology provide a completely unconstrained approach to test analysis of material functions, processes, equipments, etc. The only constraint in this area is the cost of the hardware to perform the required data gathering and analysis. The mini computer reduces the technical depth in special skills of mathematics, statistical analysis, and gives this capability to all engineering and technical personnel using the computer. The computer provides flexibility in the test set-up so that it can be modified easily, adapted to other test functions, and other devices as required. The computer has the ability to analyze the data and provide output format of information in almost format desired by the user from simple tabular listings to graphs, data, data analyzed through complex mathematical processes and so forth. The counter

balance this implied panacea to all testing is the software trap. The software aspects of the mini computer are so significant that without them, the system will not perform regardless of how sophisticated or clever the hardware has been assembled. The user should concern himself with either an interpretive assembly language such as Basic, or an operating compiler as Fortran or Algol. Insist that the mini computer supplier answers your questions in these areas, prepare a bench mark problem preferably one that you could program yourself and have the supplier perform this problem on his equipment. Talk to users of his equipment in similar equipments and determine where their pitfalls occurred so you will avoid them. With this advice well in hand, you should now be ready to go out and test the world, good luck.

R. J. BRACHMAN
U. S. Army
Frankford Arsenal
Philadelphia, Pennsylvania 19137

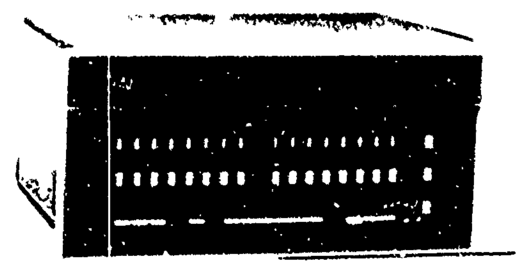


PDP-8/I

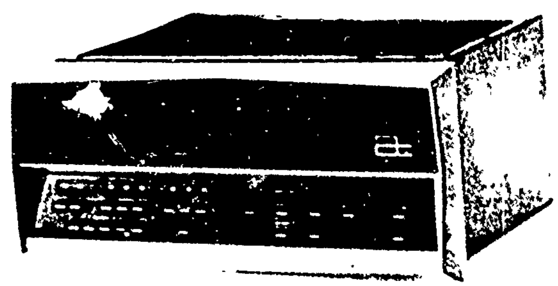


PDP-8/L

COST: $5 K to $7 K
WEIGHT: 30 lbs to 55 lbs
AVERAGE SIZE: 8 x 22 x 24 inches



520/I



PDC-808

SMALL COMPUTERS

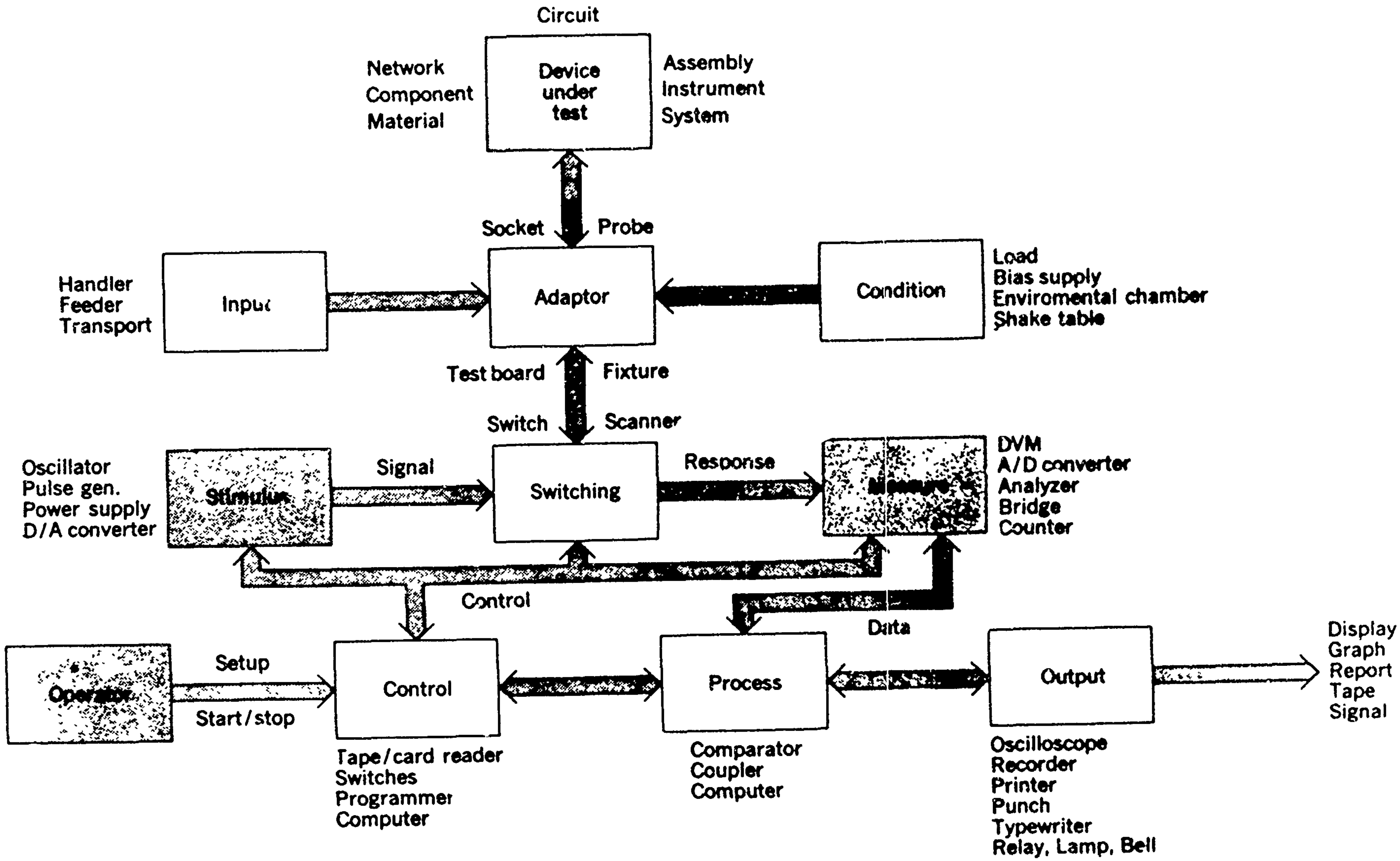


Fig. 2 **Functional block diagram of a manual or automatic measuring system.**

BASIC CONTROL FUNCTIONS	SENSING THE CONDITIONS THAT AFFECT THE PROCESS; CONTROLLING THE PROCESS; ACTUATING THE PROCESS, OR ELEMENTS OF THE PROCESS. (PROCESS INCLUDES MACHINES, TOO.)
SENSING	THE FUNCTION OF INTRODUCING THE FACTORS ON WHICH A PROCESS IS BASED, VARIABLES, PARAMETERS, AND CONSTANTS, TO THE PROCESS CONTROL SYSTEM. THIS CONSISTS OF INTRODUCING CONTROL SYSTEM INPUT DATA, EITHER AUTOMATICALLY FROM SENSORS, OR FROM MANUALLY SET CONTROLS. INSTRUMENTING IS ANOTHER TERM HAVING THE SAME SENSE AS SENSING.
CONTROLLING	THE FUNCTION OF EVALUATING THE INPUT DATA INFORMATION DERIVED FROM THE SENSORS OR "CONTROLS" AND INITIATING THE PROPER ACTION OF THE MACHINE ON LOGICAL OR MATHEMATICAL GROUNDS, OR BOTH, IN ACCORDANCE WITH THE DESIGNED MODE OF OPERATION OF THE MACHINE OR PROCESS.
ACTUATING	THE FUNCTION OF PERFORMING THE MOTION, PHYSICAL CHANGES AND ADJUSTMENTS, TO THE POSITIONS, ACTIONS, OR RESTRAINTS OF THE WORK PIECE, OR MACHINE, TOOL, OR PROCESS.

Fig. 3

SENSING	SPECIFICALLY, CONCERNS DETERMINATION OF THE LEVEL OF A CONDITION. THE FACULTY TO SENSE QUANTITATIVELY. IN GENERAL, SENSING INCLUDES DETECTION, TOO.
DETECTION	DETERMINING WHETHER OR NOT A CONDITION EXISTS OR DOESN'T EXIST. THE FACULTY TO DETECT QUALITATIVELY.
LOGIC OPERATIONS	CONTROL OPERATIONS WHICH TAKE PLACE SEQUENTIALLY IN ACCORDANCE WITH A PRE-DETERMINED "MACHINE LOGIC," WHICH ARE RULES FOR THE MODE OF OPERATION OF THE MACHINE AND HAVE A LOGIC BASIS. TIMING IS ALSO CONSIDERED TO BE A LOGIC OPERATION.
MATHEMATICAL OPERATIONS	CONTROL OPERATIONS WHICH TAKE PLACE, USUALLY SIMULTANEOUSLY, ON THE BASIS OF THE RECONCILIATION OF ANALOG OR DIGITAL REPRESENTATIONS OF THE PROCESS FACTORS, BY MEANS OF COMPUTER TYPE ELEMENTS. ALSO INCLUDES DECODING, SUCH AS USED WITH NUMERICAL CONTROL.
DISCRIMINATION	COMPARING TWO OR MORE SIGNALS AND DETERMINING THEIR RELATIVE AMPLITUDE, EQUALITY, AND SENSE.
DECISION	ARRIVING AT A LOGICAL CONCLUSION AS TO WHICH COURSE OF ACTION TO TAKE, AS BASED ON SPECIFIC CRITERIA. MACHINE DECISIONS CONCERN WHEN AND POSSIBLY WHICH, NEVER WHY OR HOW.

Fig. 4

TYPICAL MEASUREMENTS AND BASIC TRANSDUCERS

TYPE OF TRANSDUCER / QTY TO BE MEASURED	CAPACITIVE	ELECTRON TUBE	INDUCTIVE	MAGNETO-ELECTRIC	MAGNETO-STRICTIVE	PHOTOELECTRIC	PIEZOELECTRIC	RADIOACTIVE	RESISTIVE	THERMO-ELECTRIC
ACCELERATION	X	X	X	X	X		X		X	
DISPLACEMENT	X	X	X	X		X	X	X	X	
FLOW	X		X	X			X	X	X	
FORCE			X				X	X	X	
HUMIDITY & MOISTURE	X								X	
LEVEL	X					X	X	X	X	
LIGHT						X			X	X
MASS			X	X			X	X		
PRESSURE	X	X	X	X	X		X	X	X	X
TEMPERATURE						X		X	X	X
THICKNESS	X		X			X	X	X		
VELOCITY	X	X	X	X		X	X	X	X	
VISCOSITY	X				X		X		X	

Fig. 5

EQUIVALENTS

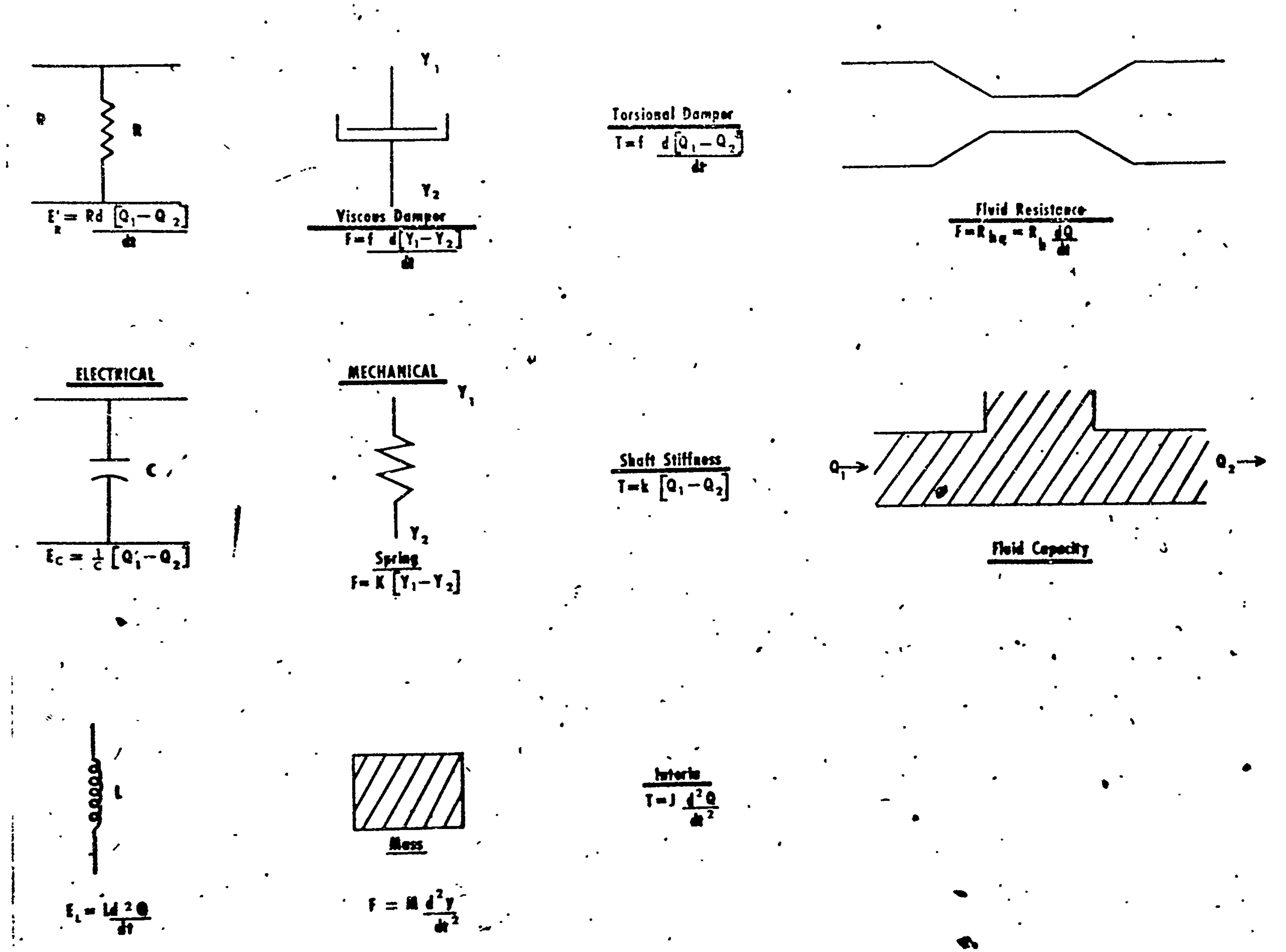


Fig. 6

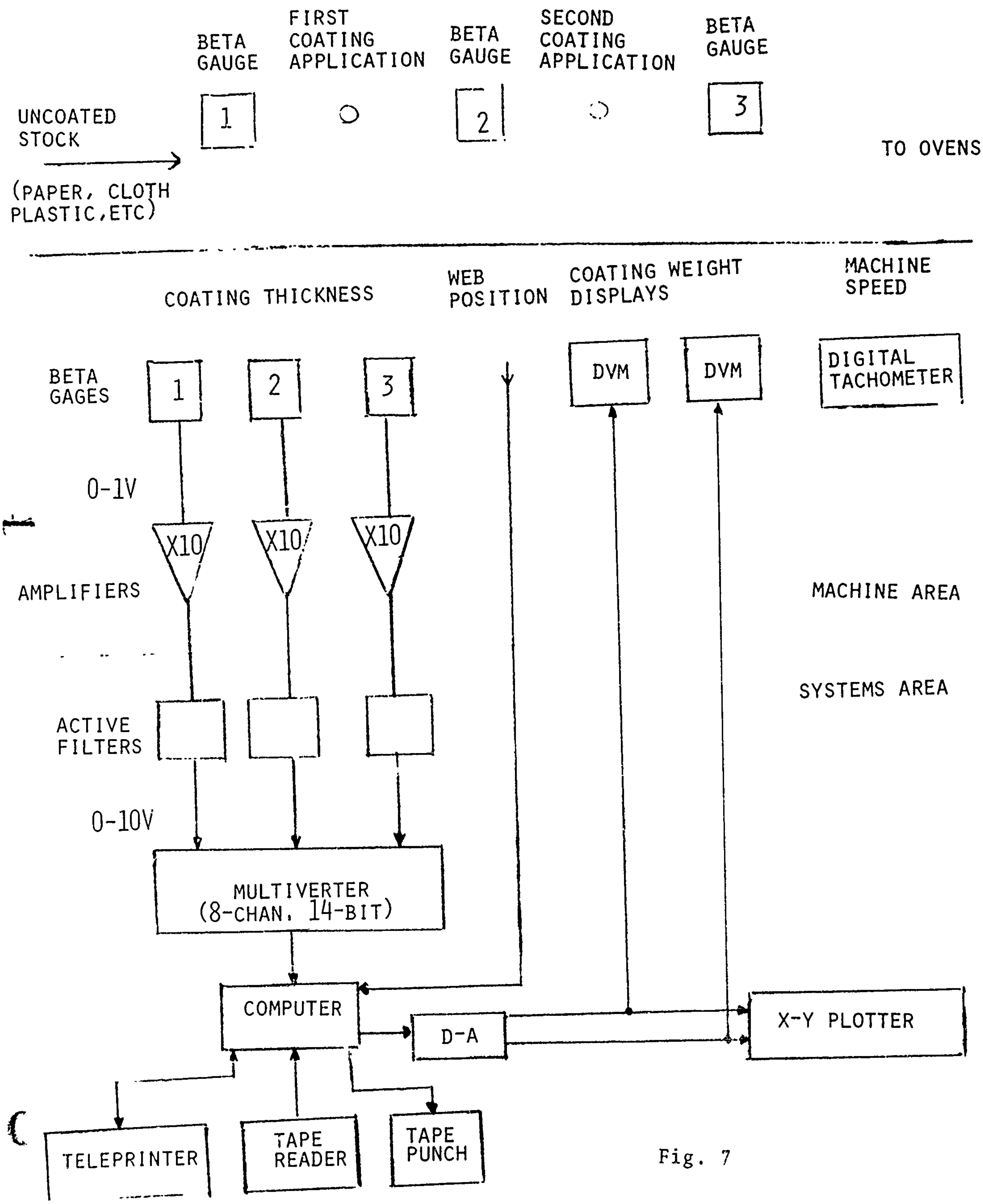

BETA GAUGE
FIRST COATING APPLICATION
BETA GAUGE
SECOND COATING APPLICATION
BETA GAUGE
UNCOATED STOCK
(PAPER, CLOTH PLASTIC, ETC)
1
2
3
TO OVENS
COATING THICKNESS
WEB POSITION
COATING WEIGHT DISPLAYS
MACHINE SPEED
BETA GAGES
1
2
3
DVM
DVM
DIGITAL TACHOMETER
0-1V
X10
X10
X10
AMPLIFIERS
MACHINE AREA
SYSTEMS AREA
ACTIVE FILTERS
0-10V
MULTIVERTER (8-CHAN, 14-BIT)
COMPUTER
D-A
X-Y PLOTTER
TELEPRINTER
TAPE READER
TAPE PUNCH

Fig. 7

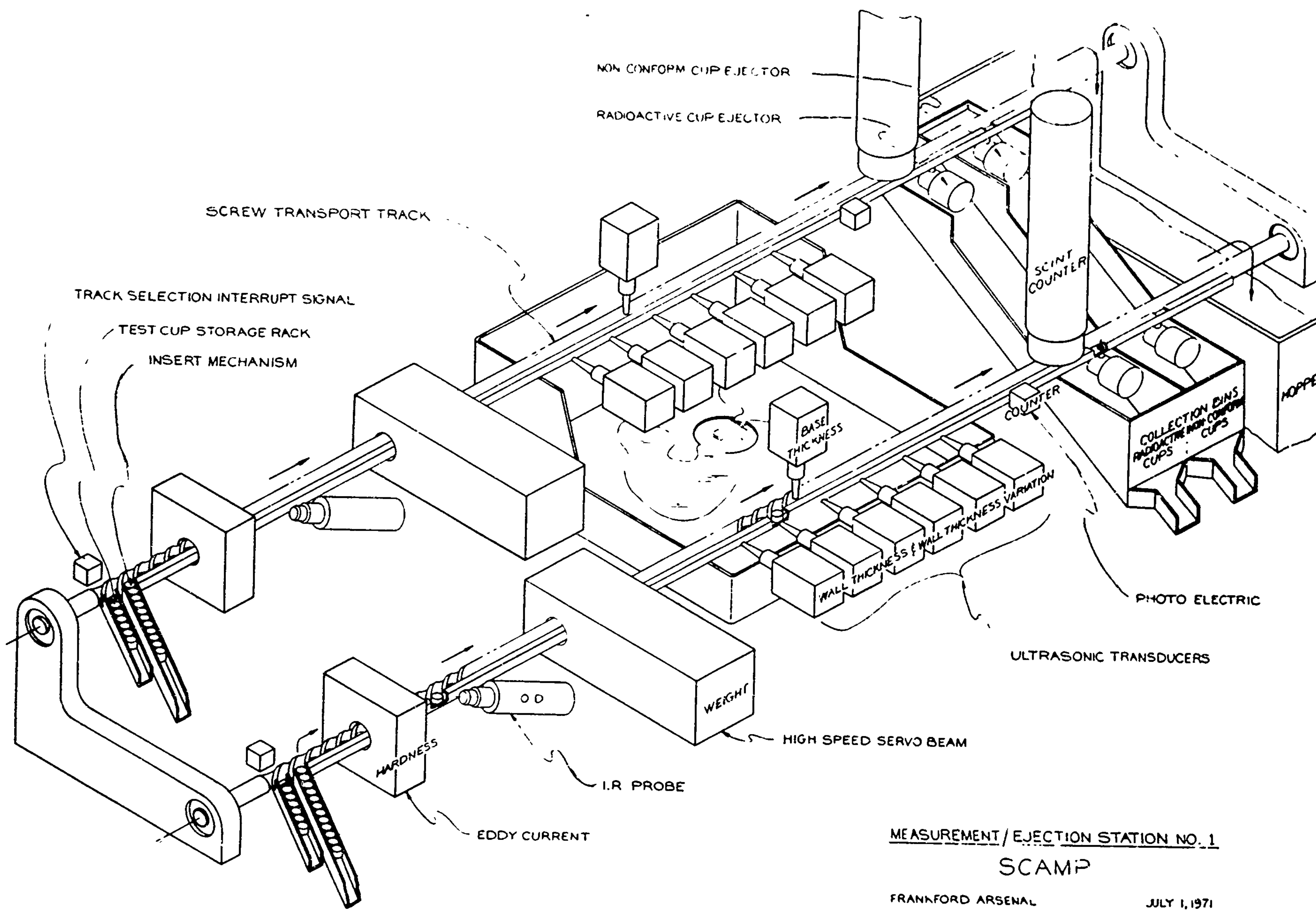
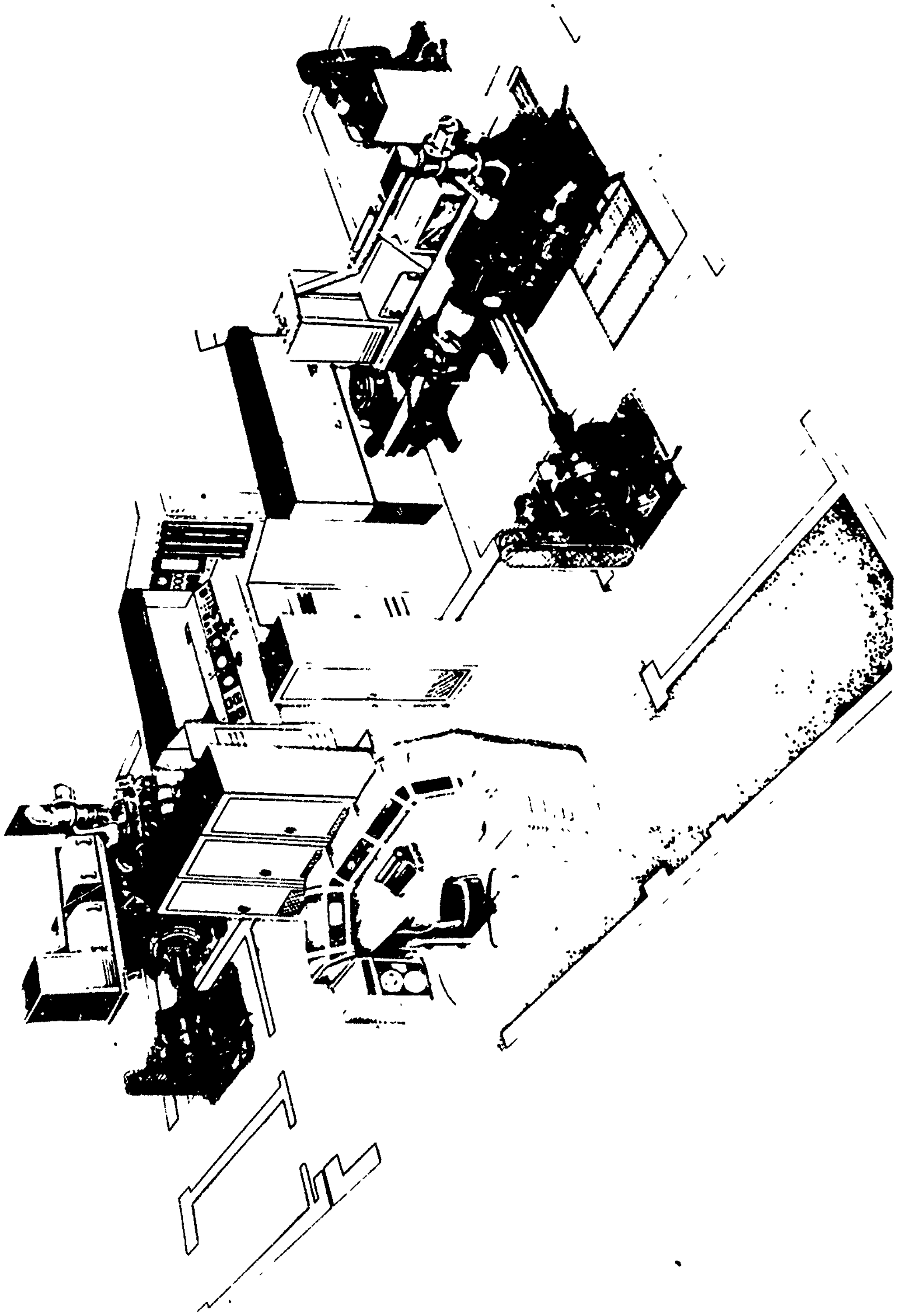

NON CONFORM CUP EJECTOR
RADIOACTIVE CUP EJECTOR
SCREW TRANSPORT TRACK
TRACK SELECTION INTERRUPT SIGNAL
TEST CUP STORAGE RACK
INSERT MECHANISM
SCINT COUNTER
COUNTER
BASE THICKNESS
COLLECTION BINS RADIOACTIVE NON CONFORM CUPS CUPS
HOPPER
WALL THICKNESS & WALL THICKNESS VARIATION
PHOTO ELECTRIC
ULTRASONIC TRANSDUCERS
WEIGHT
HIGH SPEED SERVO BEAM
O D
I.R PROBE
HARDNESS
EDDY CURRENT
MEASUREMENT / EJECTION STATION NO. 1
SCAMP
FRANKFORD ARSENAL
JULY 1, 1971

Fig. 8



DepotMAIDS

Block Diagram

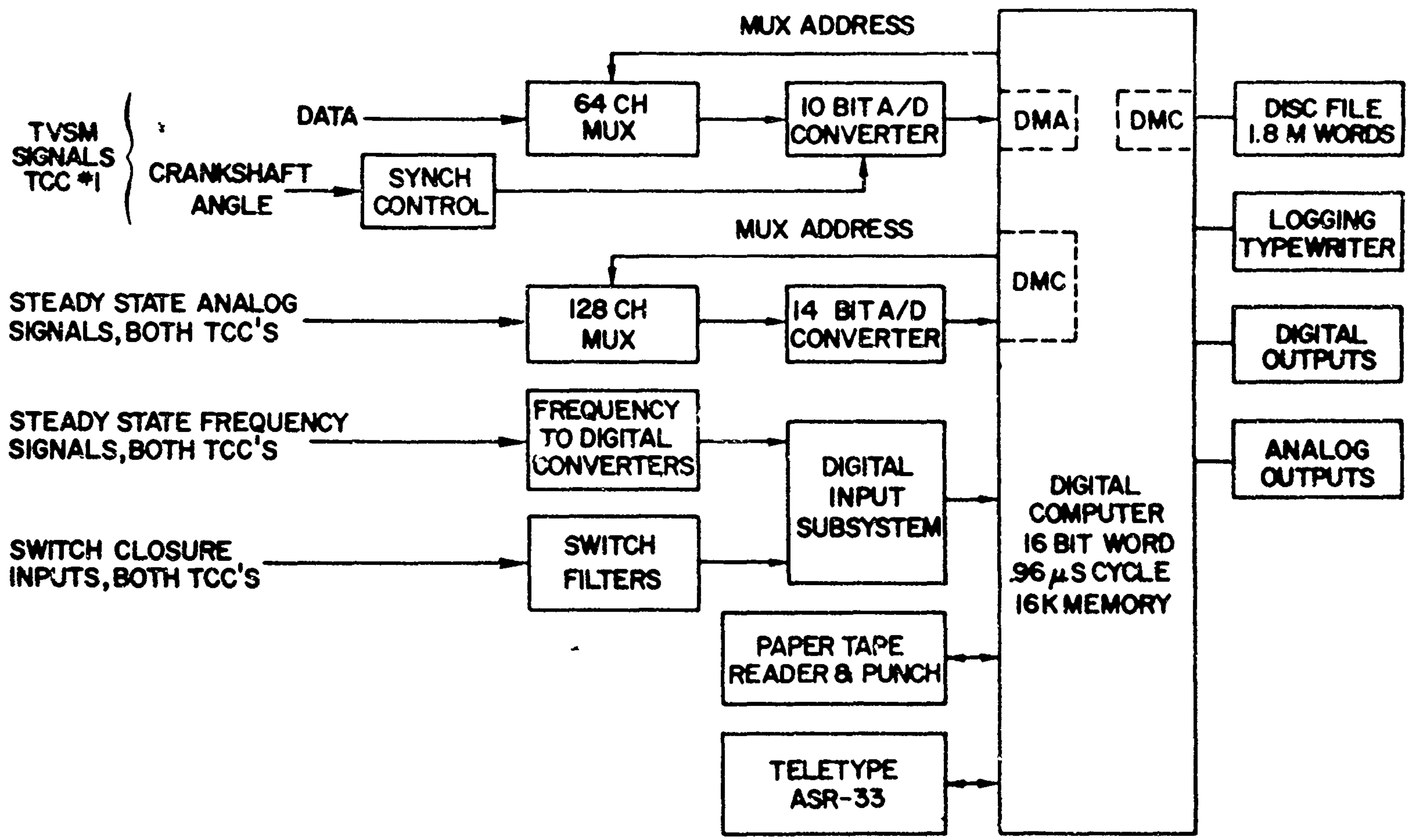


Fig. 10 Computer-Controlled Automatic Diagnostic System

MAIDS

TYPICAL DIESEL ENGINE MEASUREMENTS

MEASUREMENT	SENSOR LOCATION	ENGINE SYSTEM ANALYSIS
TEMPERATURE (25 POINTS)	(12) EXHAUST PORTS (PIPE PLUG)	POWER & INJECTORS
	(1) OIL BEFORE ENGINE OIL GALLERY (OUT OF COOLERS INTO ENGINE)	LUBRICATION AND SAFETY MONITOR
	(2) OIL COOLING LINE (OUT OF ENGINE INTO OIL COOLERS)	LUBRICATION
	(1) FUEL SUPPLY LINE (SERVICE SUPPORT SYSTEM)	CORRECTION FACTOR
	(1) FUEL RETURN LINE	CORRECTION FACTOR
	(2) OIL RETURN LINE (TURBO SUPERCHARGER)	LUBRICATION & TURBO–SUPERCHARGER
	(2) EXHAUST OUTLET (TURBO SUPERCHARGER DIAGNOSIS)	TURBO–SUPERCHARGER
	(2) INTAKE MANIFOLD (TURBO SUPERCHARGER DIAGNOSIS)	TURBO–SUPERCHARGER
	(2) INTAKE AIR FLOW (TURBO SUPERCHARGER INLET)	CORRECTION FACTOR
	(1) AMBIENT	CORRECTION FACTOR
PRESSURE (9 POINTS)	(2) INTAKE MANIFOLD (AFTER TURBO)	TURBO SUPERCHARGER AND INTAKE SYSTEM
	(1) ENGINE OIL GALLERYS (PLUG LEFT SIDE OF CRANKCASE REAR)	LUBRICATION AND SAFETY MONITOR
	(1) ENGINE OIL (OUT OF ENGINE INTO COOLERS)	LUBRICATION
	(2) AMBIENT PRESSURE (AT INTAKE TO TURBO SUPERCHARGER)	CORRECTION FACTOR
	(2) INJECTION PUMP	INJECTION PUMP, INJECTORS, TIMING
	(1) FUEL PUMP (AT INJECTION PUMP INLET)	FUEL
VIBRATION (18 POINTS)	(12) ROCKER BOX (VALVE) COVER (ACCELEROMETER)	VALVE, INTAKE & EXHAUST, ADJUSTMENT & TIMING
	(1) ENGINE BLOCK VIBRATION (BLOCK ACCELEROMETER)	INTERNAL MALFUNCTIONS (BEARINGS, ETC.)ISOLATOR
FLOWS (7 POINTS)	(1) FUEL SUPPLY LINE (DIESEL SUPPLY LINE IN SERVICE SUPPORT SYSTEM)	INTAKE & FUEL
	(1) FUEL RETURN LINE (DIESEL RETURN LINE IN SERVICE SUPPORT SYSTEM)	INTAKE & FUEL
	(1) BLOW BY (BREATHING SYSTEM)	ENGINE WEAR
	(2) ENGINE OIL (OUT OF ENGINE INTO COOLERS)	LUBRICATION
	(2) AIR–INTAKE (SUPERCHARGER)	INTAKE
CURRENT (1 POINT)	STARTER (SERVICE SUPPORT SYSTEM)	STARTER & ENGINE COMPRESSION
POSITION (1 POINT)	CRANKSHAFT	TIME BASE
SPEED (3 POINTS)	(2) ENGINE COOLING FAN (CRITICAL MALFUNCTION)	COOLING SYSTEM
	(1) ENGINE UNDER TEST	BASIC CONTROL
TORQUE (1 POINT)	(1) DYNO (TEST CELL 2)	BASIC CONTROL
THROTTLE POSITION (1 POINT)	(1) ENGINE UNDER TEST	BASIC CONTROL
VOLTAGE (1 POINT)	MAGNETO PRIMARY	IGNITION
	STARTER	IGNITION

Fig. 11

TYPICAL LOGGING TYPEWRITER DATA
DIESEL DIAGNOSTICS

ENGINE MODEL NO. 1790-2A TRANSMISSION MODEL NO. - MAGNETO TYPE NA DATE OF TEST 1-21-71
ENGINE SERIAL NO. 123123 TRANSMISSION SERIAL NO. XC

DESCRIPTION AND CODE	FED STOCK NO	ORD NO - PARTS MANUAL	QUANTITY	SECT.
STARTER CURRENT ANALYSIS			REPAIR REFERENCE - TM 9-2815-200-35	

TRUTH TABLE NAME PT0012 1B CHECKSUM 1024 DATE 6100
LIMIT TABLE NAME PL0025 CHECKSUM -28454 DATE 8070

(ABSENCE OF MALFUNCTION LIST INDICATES NO PROBLEMS)

INJECTION SYSTEM ANALYSIS REPAIR REFERENCE - TM 9-2815-200-35

TRUTH TABLE NAME PT0010 1A CHECKSUM 1032 DATE 6100
LIMIT TABLE NAME PL0022 1A CHECKSUM 13562 DATE 11050

DESCRIPTION AND CODE	FED STOCK NO	QUANTITY	SECT.
REPLACE FUEL INJECTOR 5R	2910- 64-6269	1	58
REPLACE FUEL INJECTOR 3R	2910- 64-6269	1	58
REPLACE FUEL INJECTOR 6R	2910- 64-6269	1	58
REPLACE FUEL INJECTOR 2R	2910- 64-6269	1	58
REPLACE FUEL INJECTOR 4R	2910- 64-6269	1	58
REPLACE FUEL INJECTOR 2L	2910- 64-6269	1	58
REPLACE FUEL INJECTOR 4L	2910- 64-6269	1	58
REPLACE FUEL INJECTOR 1L	2910- 64-6269	1	58
REPLACE FUEL INJECTOR 5L	2910- 64-6269	1	50
REPLACE FUEL INJECTOR 3L	2910- 64-6269	1	58
REPLACE FUEL INJECTOR 6L	2910- 64-6269	1	58

UNCATEGORIZED INDICATORS
,2- 16
INTAKE VALVE ANALYSIS REPAIR REFERENCE - TM 9-2815-200-35

TRUTH TABLE NAME PT0005 1B CHECKSUM 28672 DATE 6110
LIMIT TABLE NAME PL0012 4A CHECKSUM 9022 DATE 1131

Fig. 12

TYPICAL ASR TELETYPE RECORD-DIESEL DIAGNOSTICS

```
TCC #2 AUTO. START 14: 6:29

TEST CELL  2
STARTER CURRENT DATA
   140      0      0      0      0      0      0      0      0      0
     0      0      0     14  18687
TEST CELL  2
DIESEL INJECTOR DATA

  6056   6290   6446   6836   6564   6368   7228   6446   7032   6250
  7032   6524   6446   7032    586     41
TEST CELL  2
INTAKE VALVE DATA

   811    694    694    828    905    626   1007    687    897    475
   937    968    123    125    124    126    131    123    124    120
   125    122    122    123      0      0      0      0      0      0
     0      0      0      0      0      0    759    828    125    122
TEST CELL  2
EXHAUST VALVE DATA

   585    491    765    390    913    469    882    687    897    624
   757    811     26     27     25     33     28     27     30     29
    23     33     29     28      0      0      0      0      0      0
     0      0      0      0      0      0    602    776     27     28
TCC # 2   1800 RPM STEADY STATE DATA.
  1014    984   1044    899   1001    967   1365   1365    957   1034
   954   1049     13     85     77   -115    -43    -17    411    331
   -92   -331     -3   -316    174    196     22     22    983   1118
   111    111   1851   1837    .11   45.6    784    328    291   2841
  2844    357   2244   2410   2238   6022    105   2595   2612   1797
  3596   3442     23     24    623   .359   1008     42
TCC # 2   2400 RPM STEADY STATE DATA.
   986    973   1032   1019   1091   1059   1365   1353   1017   1141
  1077   1122   -105    -46    -27     33     59     86    288    212
  -105   -224     60   -231    181    206     25     25   1024   1177
   167    175   2900   3041   -139    467    875    408    479   2765
  2763    371   2475   2666   3059   5799    167   4115   4182   2397
  4804   4793     34     33    799    382   1017     36
TCC #2 AUTO.  STOP 14:56:55

LOGISTICAL DATA PRINTOUT
```

Fig. 13

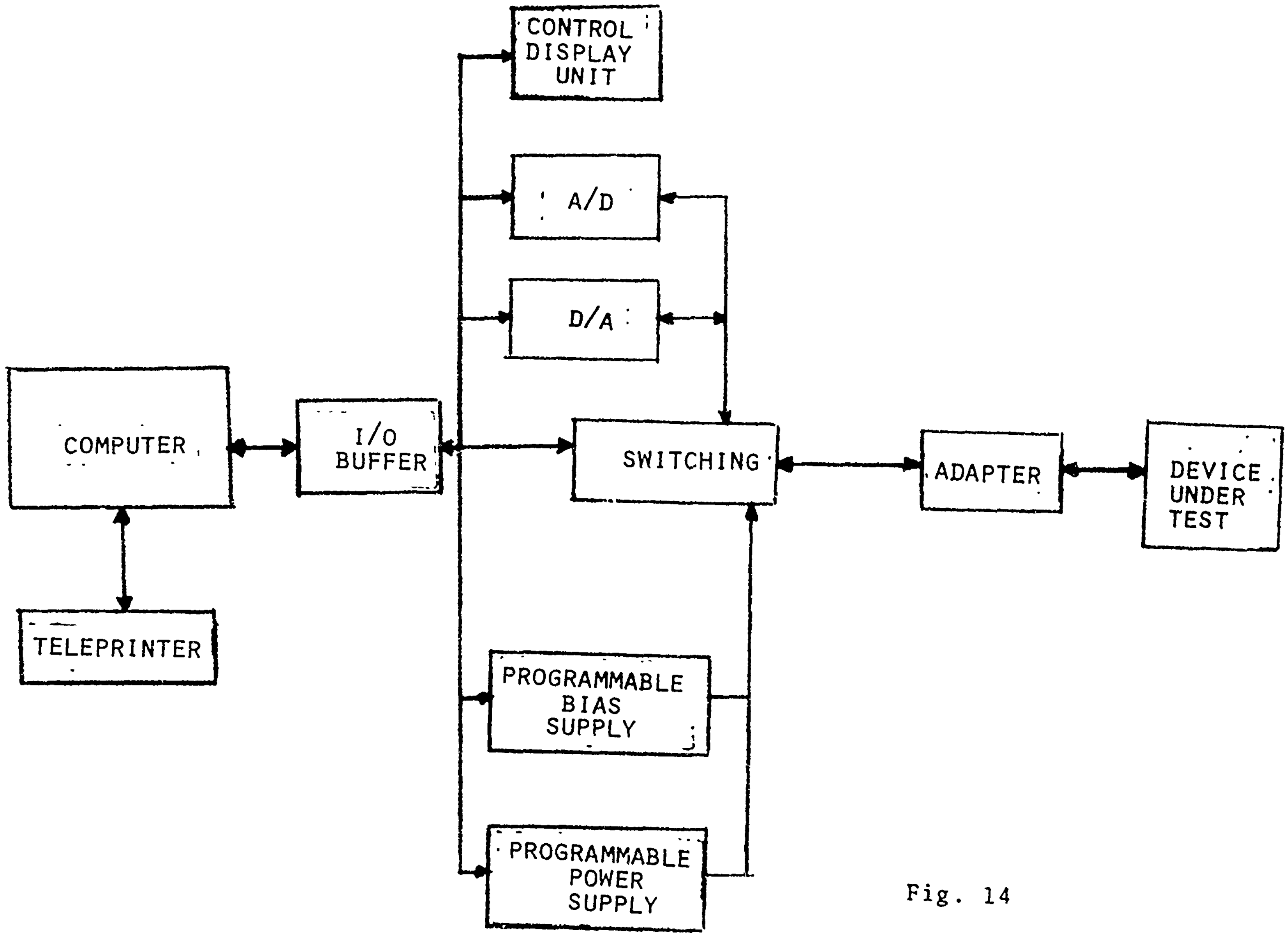

CONTROL DISPLAY UNIT
A/D
D/A
COMPUTER
I/O BUFFER
SWITCHING
ADAPTER
DEVICE UNDER TEST
TELEPRINTER
PROGRAMMABLE BIAS SUPPLY
PROGRAMMABLE POWER SUPPLY

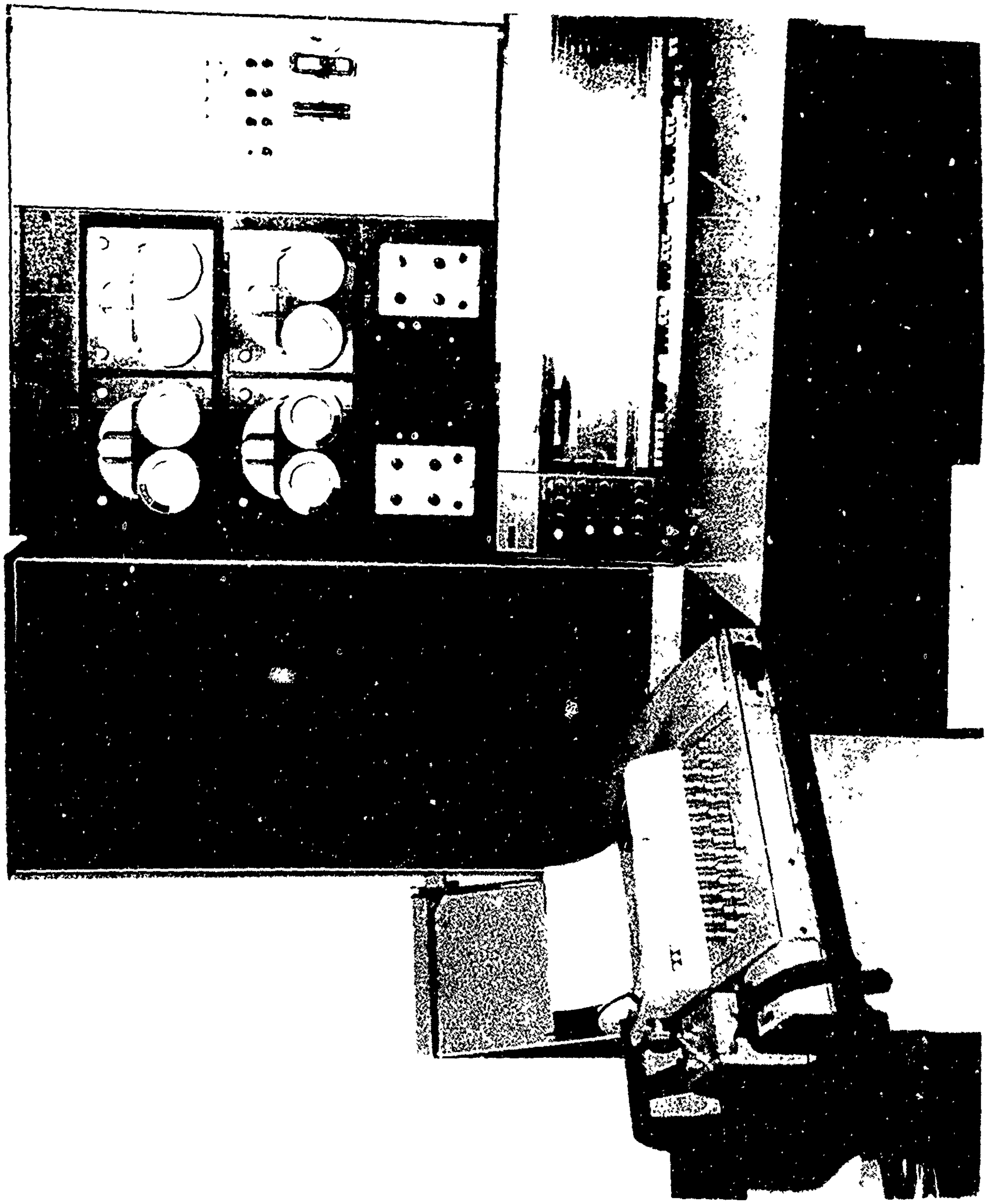
Fig. 14


THE SNOW STORM
EXECUTIVE
CODES
MACRO
LANGUAGES
COMPILERS
ASSEMBLER
BIT
OCTAL
PSEUDO
BCD
DIGIT
MICRO
REAL TIME
ENGLISH
Time Sharing
VARIABLE LENGTH
BINARY
Computer Program
TEST PROGRAM
ON LINE
CHARACTER
MULTI PROGRAMMING

Fig. 15

Machine Code	Assembly Language	FORTRAN	ALGOL
1001001011010010 1100010001000011 1111100010101100 0010001110011011 1100110010001100 0101110001101011 0100001110010101 1100001111001101 0100110101001111 1111000011001011	LOAD A ADD 5 CMP 8 JMP LABEL1 STORE C JMP LABEL2 LABEL1:LOAD B STORE C LABEL2:CONTINUE	IF(A+5-B)100,200,300 100 C=A GOTO 300 200 C=B 300 CONTINUE	IF A+5 B THEN C A ELSE C B;

Fig. 16



PAPER NO. 6

ABSTRACT

APPLICATIONS OF PORTABLE CALIFORNIUM-252 NEUTRON SOURCES FOR NONDESTRUCTIVE TESTING

S. Helf, A. Jentsch, S. Semel and J.F. McGaughey
Feltman Research Laboratory
E.G. Barnes and G.P. Drucker
Quality Assurance Directorate

Picatinny Arsenal, Dover, New Jersey

A brief review is given of the properties and advantages of neutrons for nondestructive testing applications. The availability and cost of various neutron sources (reactors, accelerators, radioisotopes) are compared. The properties of the new synthetic element californium-252 are presented and its potential as a neutron source for NDT as applied to munitions technology is discussed. A description is given of two californium-252 neutron sources and associated facilities recently acquired and being used at Picatinny Arsenal. Of particular interest is the design and fabrication of a combination shipping and storage container capable of holding up to 40 milligrams of californium-252. Specific areas of application include moisture measurement, detection for the presence and/or weight of explosive charge, chemical analysis by neutron activation and neutron radiography. Examples are given for each area of application.

Using californium-252 neutrons, it is shown that moisture content can be measured in liquids or solids down to 0.1 wt. % levels. As little as one gram of explosive charge in a sealed ammunition item can be determined by a "neutron weighing" technique. With a 10 milligram source of californium-252, elements capable of being assayed at very low concentrations by neutron activation include aluminum, sodium, copper, manganese and chlorine.

In the area of neutron radiography, a 10 milligram californium-252 source has been used for inspection of rocket warhead boosters, explosive destructors and other munitions items for which x-ray inspection had failed. Versatile neutron radiographic systems have been developed using paraffin wax and polyethylene moderators, conical collimators and a variety of film-screen combinations. The design and characteristics of these systems, as well as the ability of neutron beams to provide useful images through various thicknesses of six basic materials are reported.

INTRODUCTION

The useful properties of x- and gamma rays for nondestructive testing are by now well established. Neutrons are another form of radiation whose potential in this same area has long been known but have not been made use of until fairly recently.

The more important properties of neutrons which make them useful for nondestructive testing are:

- Metals are relatively transparent and organic materials relatively opaque to neutrons
- Many elements become radioactive when bombarded by neutrons
- Almost all elements emit prompt gamma rays upon capture of thermal neutrons.

The first property is almost the exact opposite of the behavior of x- and gamma radiation and it is this property which forms the basis of the currently growing technique of neutron radiography. This technique is rapidly becoming an important complement to x-radiography for industrial and medical inspection. The second property is the basis of the highly specialized analytical tool referred to as neutron activation analysis. Use of the third property of neutrons for practical applications has been quite recent in on-line process control and in certain field gauging problems.

The non-availability of neutron sources for general usage is mostly responsible for the relatively slow development of this form of radiation for nondestructive testing technology. The current available sources of neutrons are listed below:

1. Nuclear reactors

2. Accelerators; neutron generators

   $$H^2 + H^3 \longrightarrow He^4 + n^1$$
   $$H^2 + Be^9 \longrightarrow B^{10} + n^1$$

3. Radioisotopic

   a. (α,n) reactions

   $$He^4 + Be^9 \longrightarrow C^{12} + n^1$$

   b. (γ,n) reactions

   $$Be^9 + \gamma \longrightarrow Be^8 + n^1$$

c. Spontaneous fission

Californium-252

Nuclear reactors which provide the most intense beams of neutrons are available to only a limited number of groups for nondestructive testing purposes. These are massive installations, require large operational staffs, are very expensive to construct and operate and are certainly not portable. The least expensive nuclear reactor is a mini-TRIGA supplied by Gulf Energy and Environmental Systems, Inc., San Diego, California. These can operate at short periods of time at steady-state power levels up to 100 kw, providing a peak neutron flux of 3.5×10^{12} n/cm^2-sec. A typical mini-TRIGA costs $175,000 exclusive of building and pool but including all control and operating equipment as well as installation and start-up.

Accelerators are another source of neutrons and machines of this type designed specifically for neutron production are also called neutron generators. The most common types are based on bombardment of either tritium or beryllium targets with deuterium ions. Prices range from $15,000 to $200,000 per system depending on the total neutron yield which can be as high as 2×10^{12} neutrons per second. These costs are again exclusive of building and associated facilities. Such machines also require skilled operators, are not trouble-free and except for the very lowest neutron yield devices are not readily portable.

Radioisotopic neutron sources are radioactive isotopes which either in combination with other stable elements or by their own decay emit neutrons. The attractiveness of these encapsulated sources is their small size and weight and complete absence of operational problems. To date, the most widely used of such sources has been an intimate mixture of a light element such as beryllium with an intense alpha particle emitter such as polonium-210, radium-226, plutonium-238, plutonium-239 or americium-241. Practical small-sized sources of this type can be purchased for a few thousand dollars or less with neutron outputs up to $\sim 10^8$ per sec. Above these outputs, the (α,n) sources start to lose the advantage of small physical size and in addition to the higher initial cost, the problem of heat dissipation from the capsules arises.

Neutrons can also be produced from an intimate mixture of a light element such as berylliu' with an intense gamma-ray emitter. The most popular radioisotope for such (γ,n) sources has been antimony-124 with a half-life of 60 days. However, practical sources of high neutron output based on this system cannot be made and the accompanying high gamma dose rates are a decided 'isadva .ge for most nondestructive testing applications.

Radioisotopes that decay by spontaneous fission with the accompanying release of neutrons are usually associated with the natural elements of uranium and thorium and the man-made element plutonium. However, the

rate of decay of these elements by fission is so slow that it is only by incorporating them into nuclear piles or chain reactors that they can be utilized as intense neutron sources. In the US AEC's National Trans-plutonium Program, small quantities of elements heavier than plutonium are produced for basic research studies and to discover new elements with useful properties. One of these new elements, californium-252, is unique in that it emits neutrons in copious quantities over a period of years by spontaneous fission.

Californium-252 is made by bombarding plutonium-239 with neutrons in a very high intensity nuclear reactor. Elements of higher atomic number are built up by successive neutron captures. Thirteen successive neutrons must be added to each nucleus of plutonium-239 to convert it to californium-252. The important nuclear properties of this new element are:

Effective half-life	2.65 years
Average neutron energy	2.35 MeV
Neutron emission rate	2.34×10^{12} neutrons per sec per gram
Decay heat	38.5 watts per gram

About three years ago, the US AEC, through its Savannah River Laboratory and Plant, instituted a market evaluation program, through which californium-252 is made available to qualified recipients, on a loan basis, to explore the potential uses of this material as a neutron source. During the past year, Picatinny Arsenal acquired two such sources under this loan program and the remainder of this paper is devoted to a description of the associated facilities and the ongoing programs on nondestructive testing as applied to munitions technology.

DESCRIPTION OF SOURCES AND ASSOCIATED FACILITIES

One is a relatively small source containing 4.22 micrograms of ^{252}Cf with a neutron output of $\sim 10^7$ neutrons/sec. This source is shipped and stored in a 20 gal. metal drum filled with a lithium-paraffin wax. The source capsule whose outer dimensions are approximately 3/8" x 1 3/8", is threaded to an aluminum rod 1/4" O.D. x 8" long. This small source can be manually transferred from the storage container into an experiment (Figure 1).

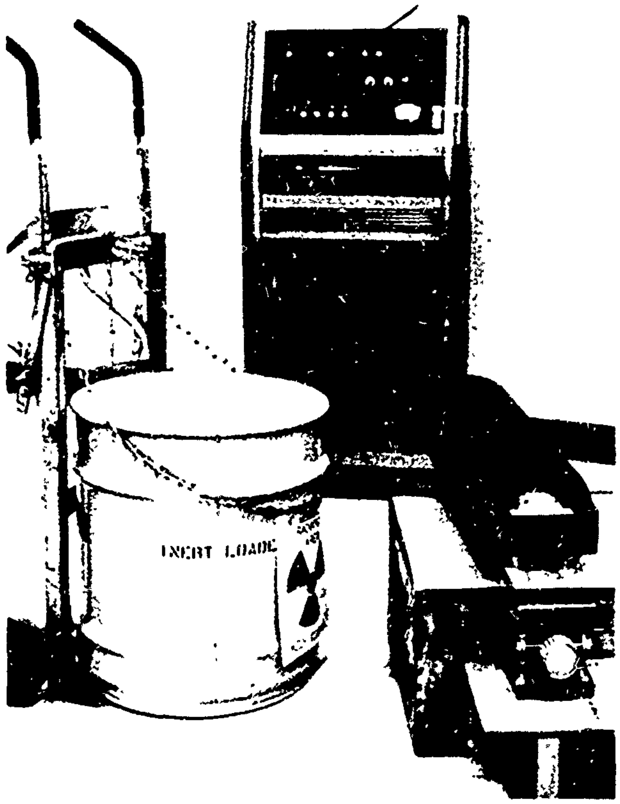
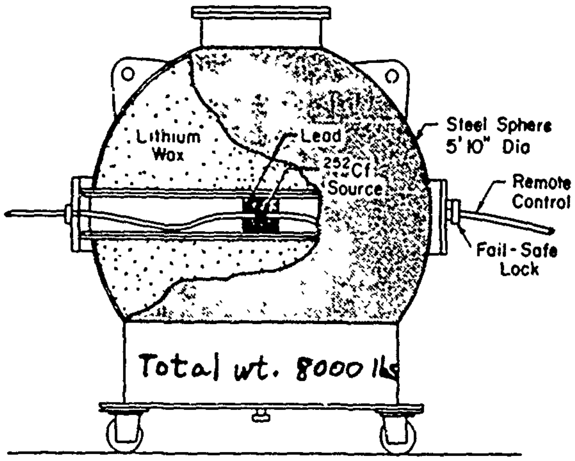


Fig. 1. Small ^{252}Cf Neutron Source ($\sim 10^7$ neutrons/sec) in Storage Container and Moisture Measurement Assembly

The second source is much more intense, containing originally 10.4 milligrams of ^{252}Cf, with a neutron output exceeding 2×10^{10} per second. Because of its relatively higher combined neutron and gamma ray output, a larger and more elaborate combination shipping and storage container was designed and fabricated at Picatinny Arsenal. This container was shipped to the Savannah River Plant for insertion of the source capsule and then transported back to Picatinny for experimentation and use.

A schematic and photograph of the container is shown in Figure 2.

The container is essentially a five-foot diameter steel cask filled with a mixture of 70% paraffin wax, 5% polyethylene powder, and 25% lithium hydroxide monohydrate by weight. The fast neutrons emanating from the source are first slowed down (thermalized) by the hydrogen atoms in the



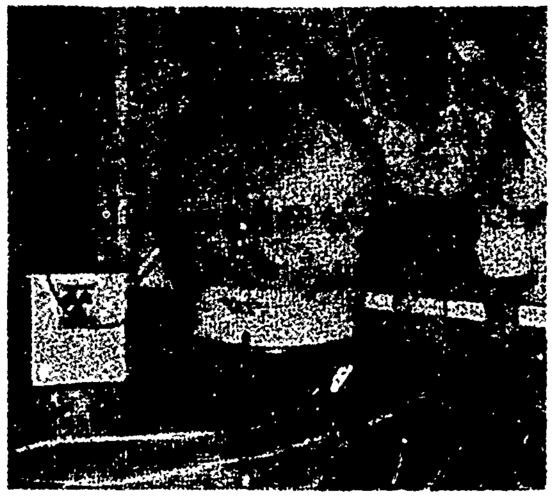


Fig. 2. Shipping and Storage Container for 10-milligram Californium-252 Source

wax and then absorbed by the lithium-6 atoms in the lithium salt. Lithium was selected as the thermal neutron absorber, rather than the more commonly used boron, because high concentrations of lithium salts are easier to disperse uniformly in molten paraffin. In particular $LiOH \cdot H_2O$ was selected because it is rich in both hydrogen (7.21%) and lithium (16.45%), is a free-flowing nonhygroscopic powder, and retains its water of hydration up to 100°C. The polyethylene powder was included because it raised the viscosity of the molten paraffin thus allowing the lithium salt to be more evenly suspended in the mixture. The shielding material in the cask has a bulk density of ~0.95 grams per cubic centimeter and a natural lithium concentration of ~38 milligrams per cubic centimeter. Absence of large voids and cracks in the solidified composition was verified by x-radiography.

A 6-inch-outer diameter stainless steel tube at the center of the cask houses a removable 5 1/2-inch outer diameter steel sleeve for the source storage and traverse assembly. This assembly consists of a rigid, curved 1/2-inch outer diameter stainless steel tube, a 4 3/4-inch outer diameter lead plug surrounding the central storage position, neutron shielding wax, and two stainless steel end caps. A modified, commercially available gamma source projection system moves the source capsule from the center of the cask to an external position and back again after use. The capsule is threaded and pinned to the end of a flexible cable which slides within a polyvinyl-covered flexible stainless steel guide tube; this guide

tube is attached to the outlet flange of the cask and connects with the curved tube inside the cask. The capsule can be moved to the desired position by turning a crank on the control unit, which is at the end of a 25-foot control cable connected to the inlet flange of the cask. An odometer in the control unit indicates the position of the source to 0.1 foot. Details of the source projection system with a dummy source capsule are shown in Figure 3.

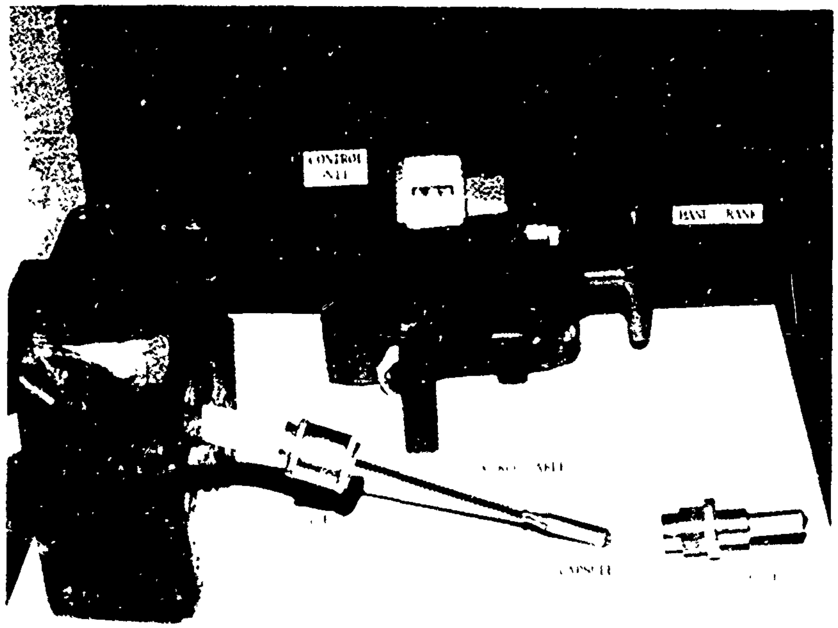


Fig. 3. Source Projection System with Dummy Source Capsule

This cask and source projection system are used in two shielded locations at Picatinny Arsenal. The flexible cables of the source projection system allows operation through bent conduits, under or through shielding, around a maze, over a barrier, down a borehole, etc. Operation is also possible in air with personnel radiation doses limited by distance alone.

The dose rates from the cask containing the nominal 10-milligram californium-252 source are:

	Dose Rate, mrem/hr	
	Neutron	Gamma
At Surface of Cask	2	40
Three feet from Cask Surface	1	9

With a few minor modifications, this storage container should be capable of holding up to 40 milligrams of californium-252 without exceeding maximum permissable external radiation dose levels.

NEUTRON APPLICATIONS

The two ^{252}Cf neutron sources are currently being used at Picatinny Arsenal for exploring the following areas of nondestructive testing:

- Activation Analysis
- Neutron Gauging

  Moisture Content
  Charge Weight in Sealed Items
- Neutron Radiography

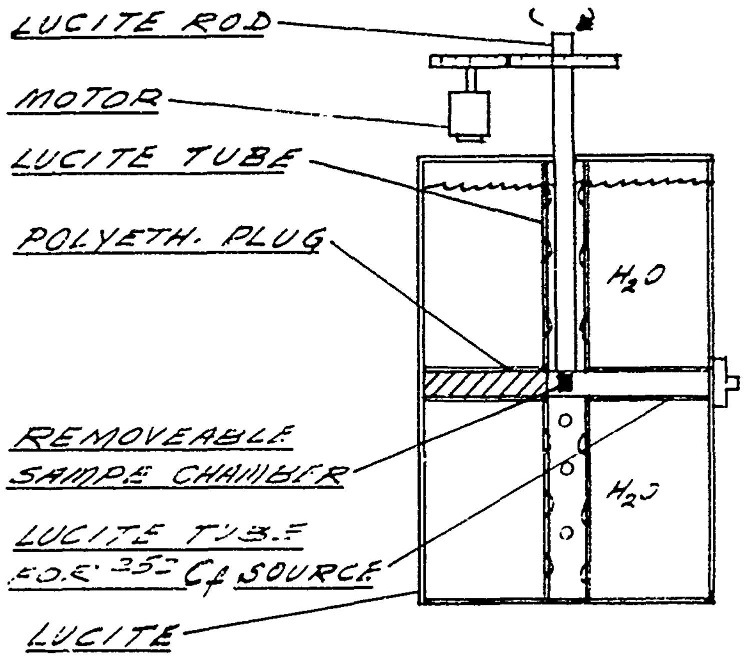
These different applications will now be briefly discussed and some examples cited.

Neutron Activation Analysis

By bombarding materials with neutrons, in particular thermal neutrons, elements comprising the material can become radioactive. In most cases the radiation emitted includes gamma rays and by measuring the energy and number of these gamma rays, this information can then be related to the identity and quantity of the elements present in the original sample. The intensity of radioactivity produced in a particular element (number of disintegrations per second) is a function of the size of the sample, the number of neutrons striking the sample or neutron flux (neutrons per cm^2 per sec) the probability of capture of thermal neutrons by the particular element (cross-section), the half-life of the product nuclide and the time of irradiation of the sample by the neutrons. The techniques of neutron activation analysis are by now well established and no further details of the principles involved will be given here.

Thermal neutron activation is generally associated with analysis for trace concentrations of elements. For this capability a nuclear reactor is required to provide the necessary intense field of neutrons. To provide a source of thermal neutrons with the 10 milligram ^{252}Cf source,

the capsule is inserted into a special water moderator. This consists of a cylindrical tank, constructed of lucite walls, approximately 6 cu. ft. in volume and filled with distilled water. The maximum obtainable thermal neutron flux with this arrangement is in the order of 1×10^8 neutrons per cm^2 per sec. A schematic of the moderator assembly and a photograph of the entire facility is shown in Figure 4.



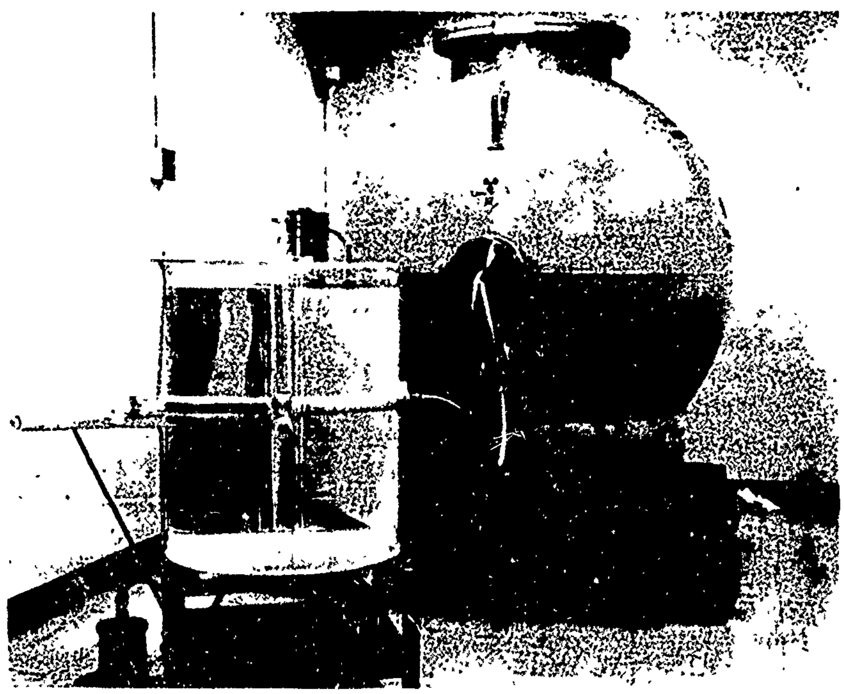


Fig. 4. Neutron Activation Analysis Facility for Use with 10 Milligram ^{252}Cf Source

With this facility and the attainable thermal neutron flux, chemical analyses can be performed at concentrations at the 0.001% level and above based on a 10 gram sample being irradiated and depending on the parameters of the particular nuclear reaction involved. A list of elements which have been and can be assayed in this facility are shown below. Included for each element is the thermal neutron capture cross-section, the half-life of the activated product element and the dominant gamma-rays emitted.

Element	Cross-section Millibarns	Half-life of Product	Gamma-ray Energy, MeV
Sodium-23	530	14.9 h	1.37, 2.75
Aluminum-27	215	2.3 m	1.78
Chlorine-37	560	37.3 m	1.63, 2.16
Potassium-41	1,200	12.5h	1.53
Chromium-50	16,000	27.8 d	0.33
Manganese-55	13,000	2.58 h	0.85, 1.81, 2.13
Copper-63	4,300	12.8 h	0.51
Copper-65	2,100	5.1 m	1.04
Bromine-79	11,400	18 m	0.62
Silver-109	113,000	24 s	0.66, 0.94
Barium-138	680	85 m	1.43

Many of these elements are constituents of explosives, pyrotechnics and propellants either as principle ingredients or impurities. The chief advantage of neutron activation is that the analysis is completely nondestructive and other tests can be performed on the same sample. In addition the method is rapid with most samples capable of being assayed in minutes.

Neutron Gauging

The attenuation, scattering or slowing down of neutrons when they impinge on or collide with particular elements is the basis of a relatively new technique which offers great potential for a wide range of nondestructive testing applications. The principles involved are essentially similar to those of neutron radiography (discussed in the latter part of this paper) except that electronic detection is used to record the signals in lieu of film imaging techniques. In this respect neutron gauging, where feasible, lends itself readily to rapid on-line high volume inspection and product control applications.

Measurement and control of moisture in ammunition materials, in particular explosives, is of continuing importance. Military specifications for moisture content for most high energy materials used in ammunition are in the order of a few tenths of one percent or less.

The availability of on-line remote control completely automated and nondestructive methods for this purpose is highly desirable. At Picatinny Arsenal, we are investigating the use of small californium-252 sources for moisture measurement and control in a variety of liquid and solid materials. The principle involved is fast neutron moderation. This technique is based on the fact that fast neutrons are slowed down to thermal energies on passing through material of high scattering and stopping power. The fractional energy loss when a neutron collides with an atom is greatest for the hydrogen atom. Therefore, a relationship is observed between the hydrogen content of a sample and the measured thermal neutron intensity.

A schematic of the apparatus used for making moisture measurement evaluations is shown in Figure 5.

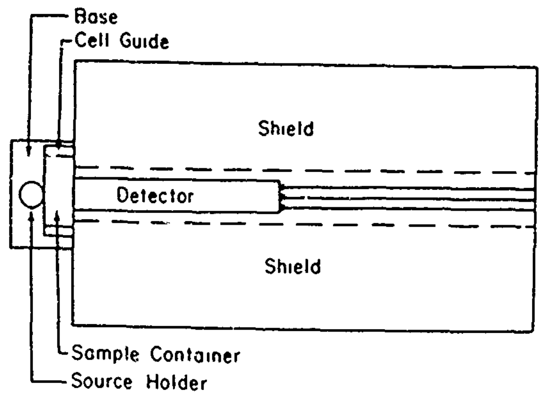


Fig. 5. Top View of Fast Neutron Moderation Measurement Assembly for Moisture Measurements (also see Fig. : for photograph)

The experimental set-up is essentially quite simple consisting of an aluminum sample cell (of varying sizes) sandwiched between the 4 microgram neutron source and the window of a shielded thermal neutron detector. The detector shield is a borated polyethylene cylinder with the inner cavity lined with a layer of 1/16" cadmium sheet. This geometry permits a high neutron counting efficiency and minimizes the detection of neutrons not originating in the sample. A lithium-6 iodide (europium activated) scintillation detector was found to be optimum as the thermal neutron detector.

As an illustration of the sensitivity of this method the determination of water content in 200 cm^3 of dimethylsulfoxide (DMSO) to which small increments of distilled water were added is shown in Figure 6. The ordinate is the difference between count rates for a completely dry sample and the wet sample. The error bars, calculated from counting statistics, represent the $\pm$ 1σ values for a single 200 sec count for each determination.

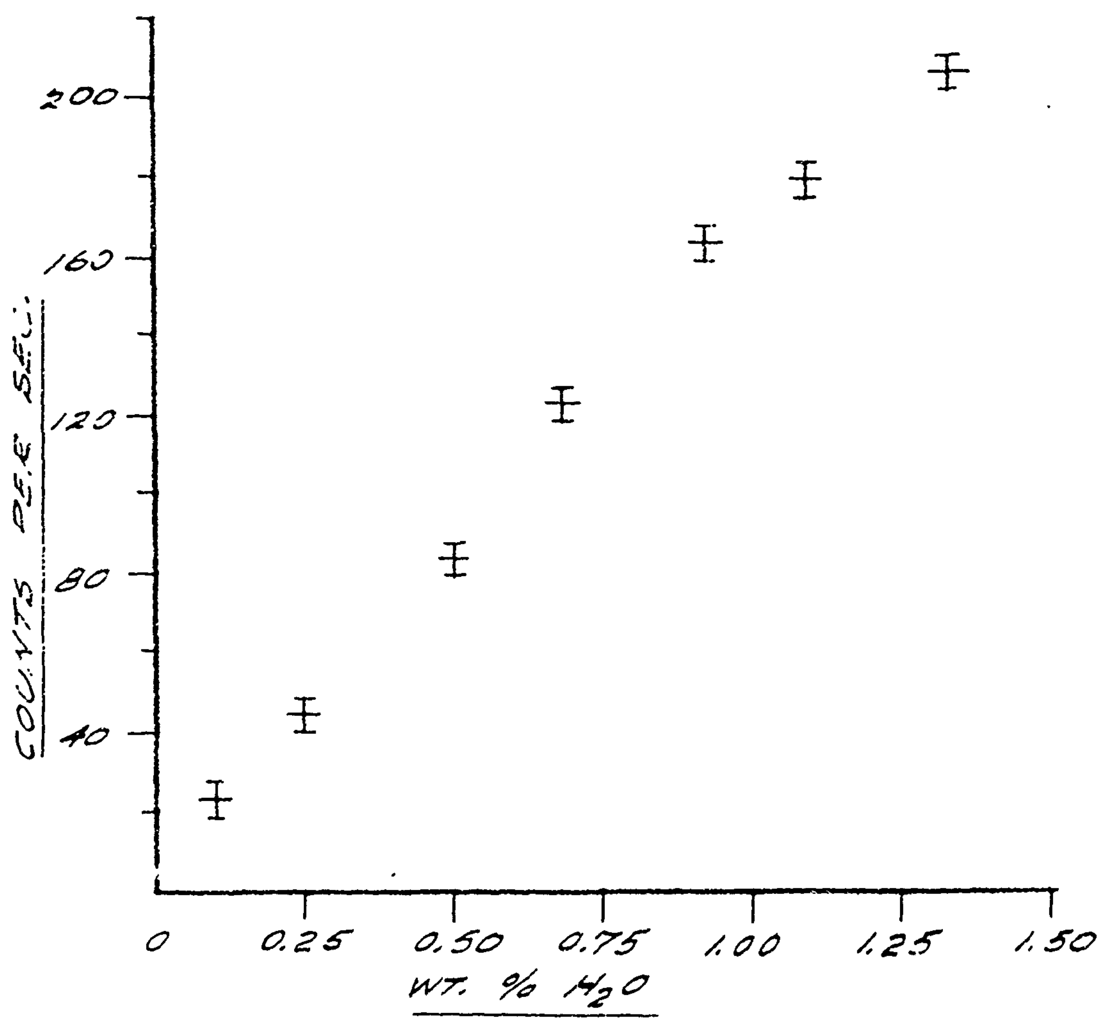


Fig. 6. Determination of Content in 200 cm^3 of Dimethylsulfoxide using a 4 Microgram ^{252}Cf Source.

Another potential application of neutron gauging is the determination of weight or volume of explosive or propellant charge in sealed ammunition items. The ability to perform this operation has long been considered a critical and challenging problem for Ordnance technology. Correct charge weight in a large spectrum of munitions items is not only important for proper functioning of the particular item but of even greater importance it is essential for the safety of the man firing the weapon. A critical factor that has prevented the successful development of workable charge weight inspection methods in sealed items is that the variation caused by tolerances in the metal components often masks the variation in charge weight tolerance. It is here that

neutron techniques are especially attractive because of the lower sensitivity of neutrons to attenuation by most metals used in ammunition as compared to the lower density explosive and propellant charges.

Investigation of "neutron weighing" applications at Picatinny Arsenal has just recently started. However, the feasibility of the technique is illustrated by the data shown in Figure 7. In this experiment, a 1/32" brass-walled cylinder, 2" long and 5/8" O.D. was filled with water in one gram increments and the change in thermal neutron count rate was recorded. (The apparatus used was the same as depicted in Figure 5.)

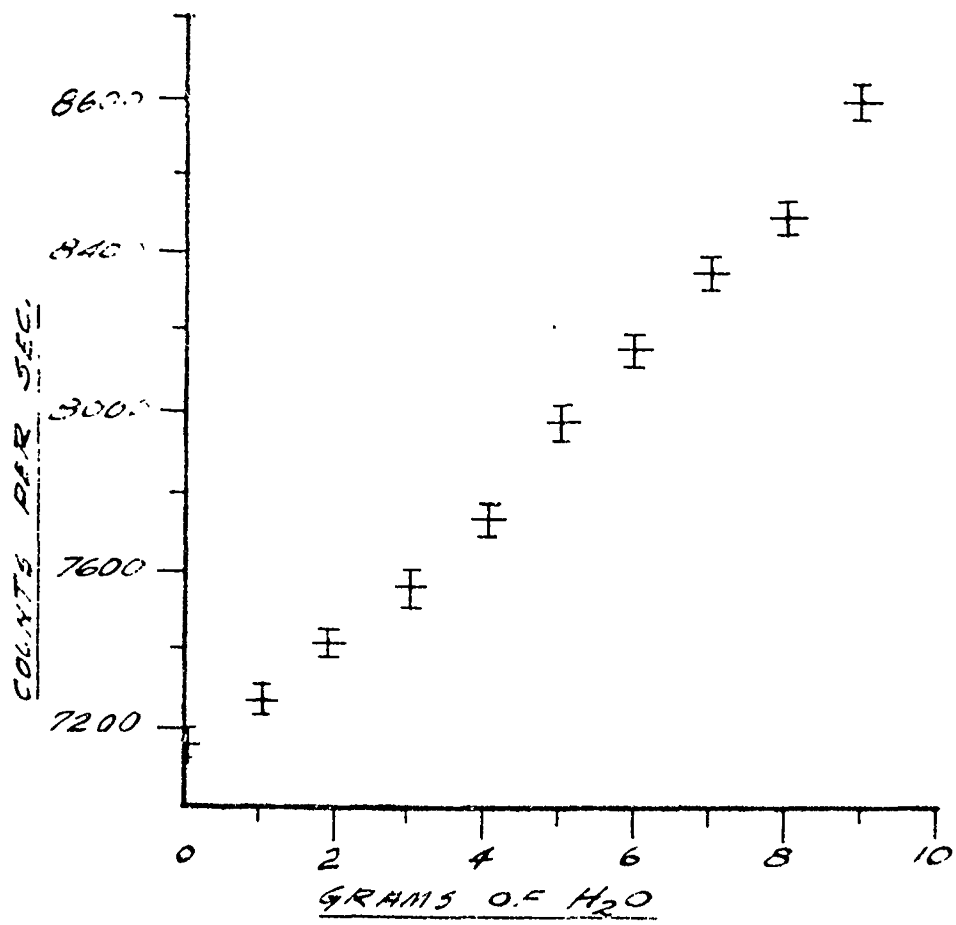


Fig. 7. Neutron Gauging Experiment for Determining Charge Weight in a Sealed Brass Cylinder (error bars indicate $\pm$ 1σ for a 100 sec count).

Neutron Radiography

The possibility of using beams of neutrons to form images, as is done with x-rays, was recognised in the early 1930's, and a few experiments in this area were performed in Germany in 1937-39. It was not until the 1960's, however, that concerted efforts began to make neutron radiography a practical nondestructive testing method for industrial application. It was during this time that interest was aroused at Picatinny Arsenal in the possibility of using this new technique for inspecting munitions items and materials.

The potential value of neutron radiography becomes apparent if one considers how a radiograph is produced and how the various parameters affecting image formation are changed by switching from x-rays to neutrons. In either case, a source of radiation is required, which illuminates the specimen under examination, casting a shadow onto some imaging medium. (Fig. 8) Usually this medium is photographic film or a fluoroscopic screen. Hopefully, the radiation has penetrated the object, and the shadow image contains outlines not only of outer boundaries of the specimen, but also of some desired internal features.

The image on a film is made up of variations in optical density from point to point across its surface. These density variations result directly from variations in the intensity of the radiation beam penetrating the specimen, and it is this intensity which must be controlled if one is to obtain useful images of the internal features of objects. Figure 9 shows the basic physical properties which govern the penetration of radiation through an object having both thickness and material variations. Thickness and physical density are both totally dependent on the object, and are usually not within the radiographer's control. Mass absorption coefficient depends on the elements in the object, but it is also a function of the type and energy of the penetrating radiation employed. Therefore, we can effect a measure of control over what is shown in a radiographic image by manipulating mass absorption coefficients through (1) changes in radiation energy, or (2) switching from one type of radiation to another.

Figure 10 compares the mass absorption coefficients of most elements (identified by atomic number) for both thermal neutrons and a typical energy of x-rays. A higher coefficient indicates a greater ability to absorb or prevent the transmission of the impinging radiation. It is easily seen that, unlike x-rays, neutrons do not exhibit orderly relationship to atomic number and they are preferentially removed from a beam by the low atomic number elements, particularly hydrogen. In addition, there are a certain few elements including cadmium and gadolinium with extrodinarily high mass absorption coefficients. Neutrons, therefore, offer three distinct potential advantages over x-rays for nondestructive testing by radiography:

(1) clearly defined images of hydrogen-containing materials (plastics, rubber, oils, water, explosives, etc.) contained within most commonly used metals;

(2) discrimination between two or more elements closely related in atomic number and density;

(3) imaging of materials or components to which trace amounts of neutron absorbers, such as gadolinium, had been added.

Figure 11 translates mass absorption coeffecient into a practical measure of the penetrating ability of neutrons and of x-rays at two common energies for several representative materials. It shows the thickness of each indicated material that is required to provide an amount of attenuation equivalent to one inch of iron.

It was the possibility of obtaining significantly improved inspection of explosives and other organic material surrounded by metal shells that was especially appealing to Picatinny Arsenal and led us into an active program in neutron radiography. In 1970 we began a project under the Army Material Command's Materials Testing Technology program to evaluate neutron radiography for inspection of munitions items and materials. The project includes experiments and the development of apparatus needed to demonstrate applications of real value in the munitions field, to make comparisons with conventional x-ray methods, and to determine the equipment and techniques most likely to provide a practical, general purpose neutron radiographic system.

Early work in the program was based on the use of the sealed tube 14MEV neutron generator, which was already available in house. The first job was the construction of a moderator, the use of which is illustrated in figure 12. The most useful neutrons for radiography to date are thermal neutrons; that is, neutrons that have been allowed to come into thermal equlibrium with the molecules of their environment. The neutrons emitted by the primary source are always of high energy, and must be brought down to thermal energies by successive collisions with atoms in the moderator. A portion of the neutrons being scattered in this way within the moderator are then allowed to pass through the collimator and to impinge on the specimen.

Preliminary work with the neutron generator reached the point of producing some fairly readable radiographs, but, with the advent of the Cf-252 source, this work was curtailed. The paraffin wax moderator used with the neutron generator was modified for californium operations and is still being used. It will later be replaced with a polyethelene moderator of improved design. The current wax moderator was constructed by simply standing together, face to face, a number of slabs of commercial paraffin, and drawing them together with four long, wooden dowel pins. Drilling and fitting of the individual slabs was performed using wood working tools prior to final

assembly, and the ease of working the paraffin permitted the construction to progress rapidly. Additional paraffin slabs were taped to the sides and top of the assembly to form a cube measuring roughly 2 feet on each side. The moderator (figure 13) is oriented to provide a horizontal thermal neutron beam through a conical collimator. The californium-252 source guide tube is inserted to the center of the moderator via a cylindrical hole directly opposite and along the same axis as the collimator.

The collimator is a cone of .060 inch thick cadmium lining the inner wall of the conical hole in the paraffin moderator. It forms an aperture 2 inches in diameter at the center of the moderator and spreads to 6 inches in diameter at the face of the moderator. To reduce gamma ray contamination in the neutron beam created by neutron capture in cadmium and hydrogen, the inner wall of the cadmium cone has been lined with a 0.25 inch thick cone of lead.

To further reduce the unwanted gamma ray component reaching the film plane, 1 inch of bismuth filtration (in the form of two plugs, each 0.5 in. thick) was placed in the collimator adjacent to the inner aperture. Also, a flat, 5/8 inch thick lead gamma shield was added to the face of the moderator around the collimator opening. It was considered necessary to shield the entire face of the moderator, since 2.2 Mev gamma rays would be generated throughout the mass of paraffin by thermal neutron capture by hydrogen.

Another device to improve the quality of the thermal neutron beam reaching the film plane is a shield to absorb stray neutrons emanating from the face of the moderator. For this purpose a 6 inch thick lithium loaded paraffin slab (50% lithium hydroxide monohydrate by weight) was used with a tapered hole at the center to permit passage of the desired neutron beam. In effect, this shield is an outward extension of the collimator, but without the undesirable side effect of prompt gamma ray emission due to thermal neutron capture since lithium produces almost no gamma rays upon neutron capture.

All neutron radiographic exposures to date have been made with the film at 40 inches from the 2 inch inner collimator aperture, providing an L:d ratio of 20. The useful diameter of the neutron beam at this distance is about 15 inches. The important neutron and gamma characteristics of the system are shown in Table 1. Figure 14 shows the californium storage cask and the neutron radiographic system set up for a typical exposure, except that film cassette was omitted.

A variety of film-screen combinations have been tested, including both wet processed and Polaroid film and with both gadolinium foils and scintillator imaging screens. All exposures on wet processed radiographic film were made in a standard, spring loaded cassette with magnesium front,

A lead foil filter .030 in. thick was added to the outside of the cassette front to attenuate the lower energy gamma rays in the neutron beam. Three gadolinium screens of different sizes and construction and a small lead screen .005 in. thick were mounted in the cassette to be in contact with the back of the radiographic film. The characteristics of the gadolinium screens were as follows: a 6 in. x 10 in. rolled metal foil .003 in. thick; a 1 in. x 3 3/4 in. rolled metal foil .001 in. thick; and a 2 in. x 2 in. metal layer 10 microns thick vacuum deposited on an aluminum backing and having an 85 millimicron overlayer of fused silica. By exposing a common film to all these screens simultaneously, it was possible to compare their responses to both neutrons and gamma rays. The lead screen furnishes no response to neutrons, and therefore provides a built-in indicator of gamma ray contamination in the neutron beam.

Initial qualitative evaluation of the three gadolinium screens indicated no major differences in thermal neutron sensitivity or image resolution. An exposure to 1,000 kilovolt x-rays showed considerably less film darkening from gadolinium than from lead. As expected, the x-ray response of gadolinium is dependent on the thickness of the layer, the thinner layer providing the least response as indicated by film darkening. In the cases of both gadolinium and lead, whether exposed to neutrons or x-rays, film exposure is provided mainly by electrons emitted from the surface of the metal.

Most of the neutron radiographs made in our program this far have been with exposures of one to two hours using DuPont NDT-75 film on which only one emulsion had been coated. By avoiding use of the front emulsion, a noticeable gain in resolution and reduced gamma sensitivity was achieved, even with a fast, relatively coarse grained film. Exposures made with the single emulsion to the front of the cassette, placing the film base between emulsion and conversion screens, showed extremely light, poorly defined images with higher gamma response than the normal back emulsion exposures.

The best resolution and overall image clarity to date have been produced with Kodak type R single emulsion film and gadolinium back screens. Exposures with this slower, fine grained film have run about 16 hours.

Lithium -6 loaded zinc sulfide scintillator screens were used with both wet processed radiographic film and with Polaroid photographic film. All the scintillator images have the very mottled appearance and extremely low gamma ray response typical of these materials. One scintillator screen was fitted to a standard 4 x 5 inch Polaroid film holder, and was used as a front screen. Exposure times for Polaroid film ranged from 10 minutes with type 52 film down to 10 seconds with type 57. The extreme granularity of the images on the faster film makes it unsuitable

for examining most items of interest. However, the scintillator in combination with the finer grained Polaroid film does provide clear enough images for some applications, and even the faster film is adequate for making quick checks on the effects of changes in equipment and techniques.

Specimens used in our experiments consisted of specially fabricated step wedges and models, as well as a number of existing munitions components. Figures 15, 16, and 17 are positive prints of neutron radiographs showing several of these items, details of which are described in Appendix I.

Our investigation to date shows that neutron radiography can provide critical inspections of munitions items not attainable by x-ray or any other nondestructive tests. We have neutron radiographically inspected over 600 items with our californium radiographic system, and have only scratched the surface of potential applications. It now appears practical to consider the use of neutron radiography for inhouse examination of R&D and engineering items where long exposure times and low production are not significant factors. However, since exposure times remain long and the cost of buying and maintaining neutron sources are extremely high, neutron radiography cannot be considered to have reached the state where it can be put into general use along side x-ray or gamma radiography. Our efforts are continuing to improve this picture, and it is almost certain that as new applications are identified and as prospective users make their requirements known, the cost of neutron sources, and consequently of neutron radiography, will be steadily reduced.

S. HELF/A. JENTSCH/S. SEMEL/J. F. McGAUGHEY
Feltman Research Laboratory
E. G. BARNES/G. P. DRUCKER
Quality Assurance Directorate
Picatinney Arsenal
Dover, New Jersey 07801

APPENDIX I - Description of Neutron Radiographs, Figures 15, 16, and 17.

Figure 15. The hand grenade fuse, adapter, cartridge case, and squib switches are all standard components of munitions items and were selected to demonstrate the ability of neutron radiography to show low density, organic materials inside metal enclosures. All of these items are routinely examined by x-ray radiography, but the neutron images show distinct improvements in sensitivity in all cases. The steel step wedge shown in figure 15 ranges from 1/4 to 1 1/2 inches thick in 1/4 inch increments. Clearly showing through the 1/4 inch step are four explosive (TNT) rods down to 1/32 inch in diameter. A fifth rod 1/64 inch in diameter is barely visible on the original radiograph. On the original, the 1/32 and 1/16 inch diameter TNT rods are detectable through the 1 inch step; the 1/8 and 1/4 inch rods can be seen through the 1 1/4 inch step. The same explosive rods were also exposed with step wedges of lead, aluminum, and brass, all of which showed the 1/64 inch rod through at least 1 inch of the metal. Munitions items are commonly constructed with these metals surrounding thin sections of explosive materials, and the ability to radiographically inspect the internal explosive is important to assuring their safety and reliability.

Figure 16. This compares x-ray (top) and neutron radiographs (bottom) of 40mm cartridge cases with respect to their ability to show the level of propellent powder within their propellent cups. Even on the original negatives, x-rays gave very poor images, and propellent level could only be seen by the most experienced film readers. The full, partially full, and empty conditions of the three cartridges are obvious on the neutron radiographs.

Figure 17. These steel cased, explosive boosters were x-rayed to assure presence of explosive filler in both the large inner cavity and the small cup on the end. The condition of the large cavity could be determined with difficulty, but no refinements in x-ray technique could show any difference between known full and known empty end cups. The neutron radiographs show the difference at a glance, and even small voids in the explosive can be observed.

TABLE 1

Characteristics of a Neutron Radiographic Device Using ^{252}Cf and Paraffin Moderator

Source Size, mg	10.4
Total Neutron Yield, n/sec	2.5×10^{10}
Peak Thermal Neutron Flux at Moderator Center, n/(cm^2-sec)[a]	1.14×10^8
Ratio of Yield to Peak Thermal Flux	2.18×10^2
Thermal Neutron Flux at Film Plane (40 in.), n/(cm^2-sec)[a]	1.2×10^4
Cadmium Ratio at Moderator Center[a]	5.1
Cadmium Ratio at Film Plane[a]	2.1
Gamma Dose Rate at Film Plane, mR/sec[b]	2.4×10^{-1}
Neutron-to-Gamma Ratio at Film Plane, n/(cm^2-mR)	5×10^4
Length-to-Diameter Ratio	20

a. Measured by gold foil activation, collimator in place.

b. Measured by self-reading calibrated pocket ion chambers.

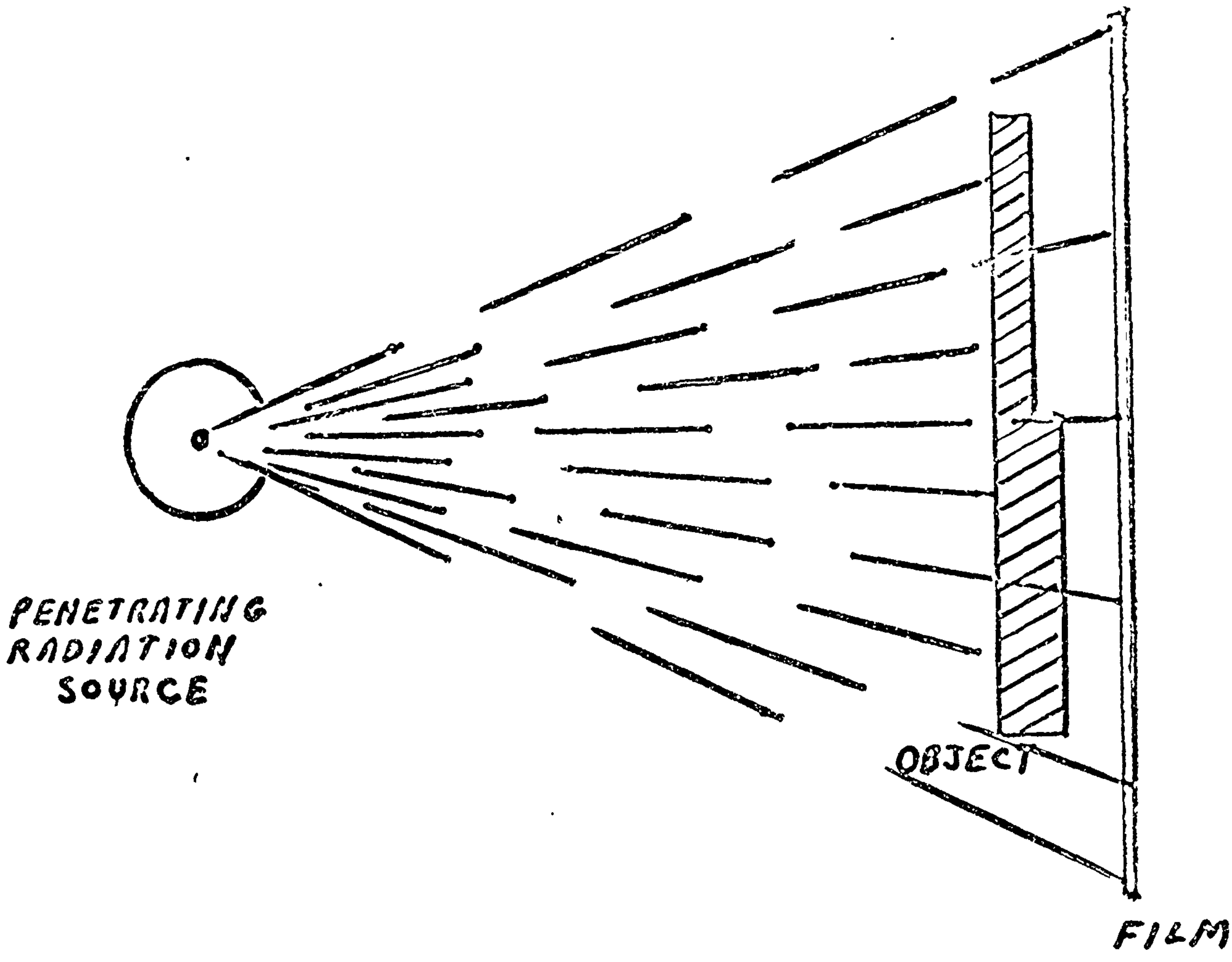
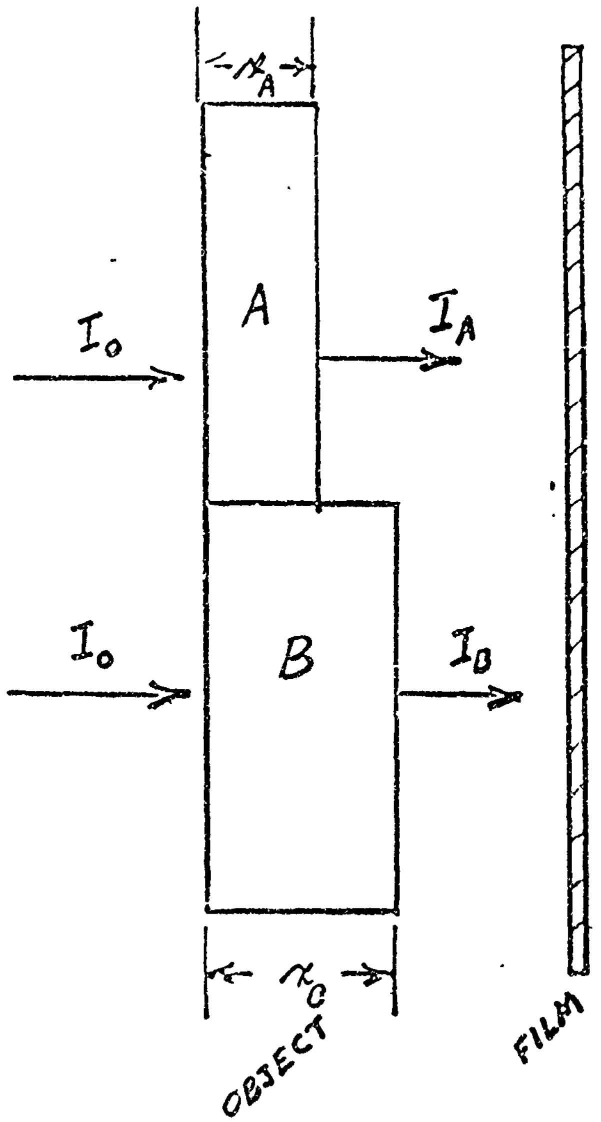


Fig. 8



$$I = I_o e^{-\rho\sigma x}$$

ρ = DENSITY

σ = MASS ABSORPTION COEFFICIENT

x = THICKNESS

FILM CONTRAST $\sim \frac{I_A}{I_B}$

$$\frac{I_A}{I_B} = e^{-(\rho_A \sigma_A x_A - \rho_B \sigma_B x_B)}$$

ρ, x FIXED BY OBJECT

σ RADIATION DEPENDENT

Fig. 9

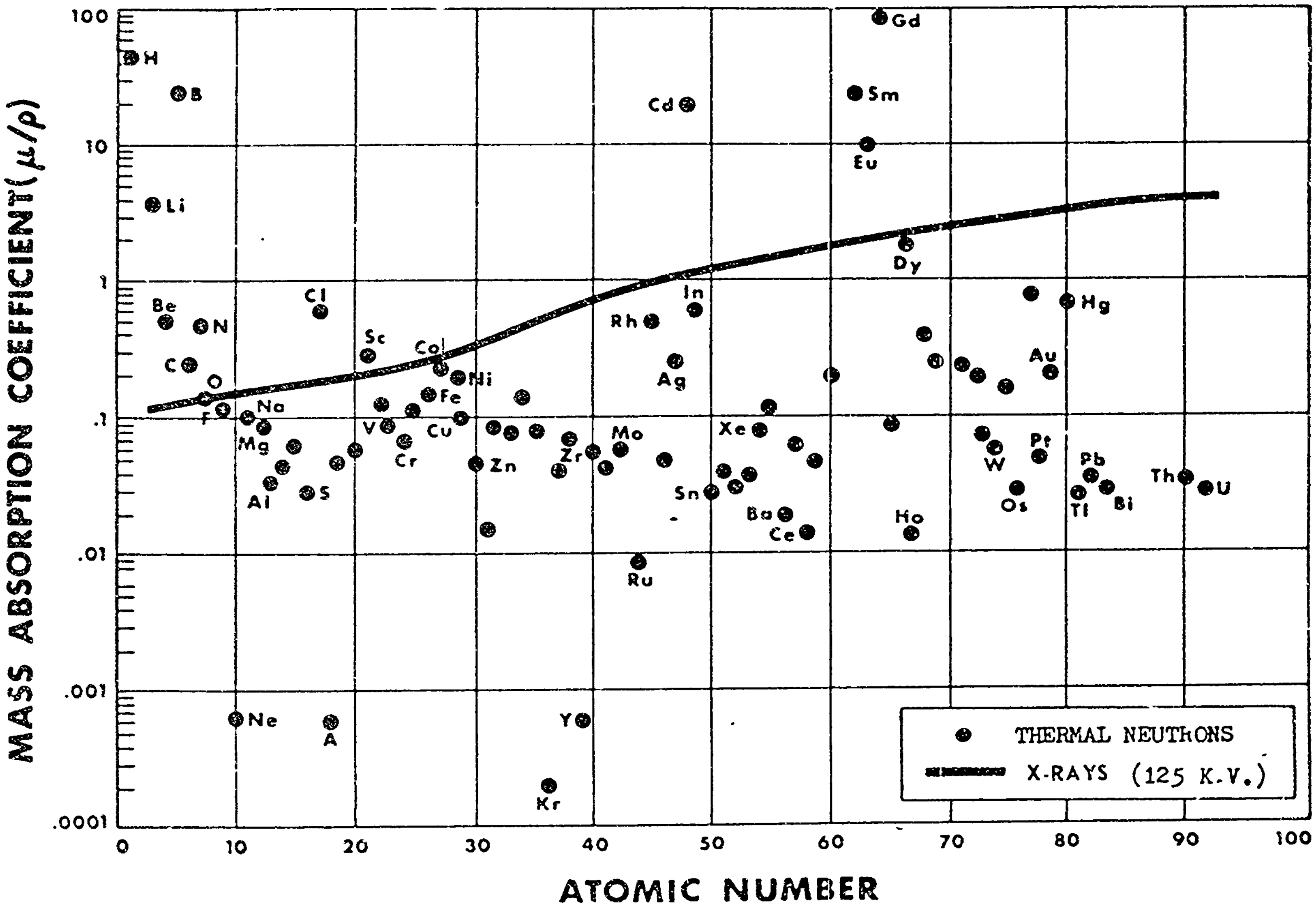


Fig. 10 COMPARISON OF MASS ABSORPTION COEFFICIENTS

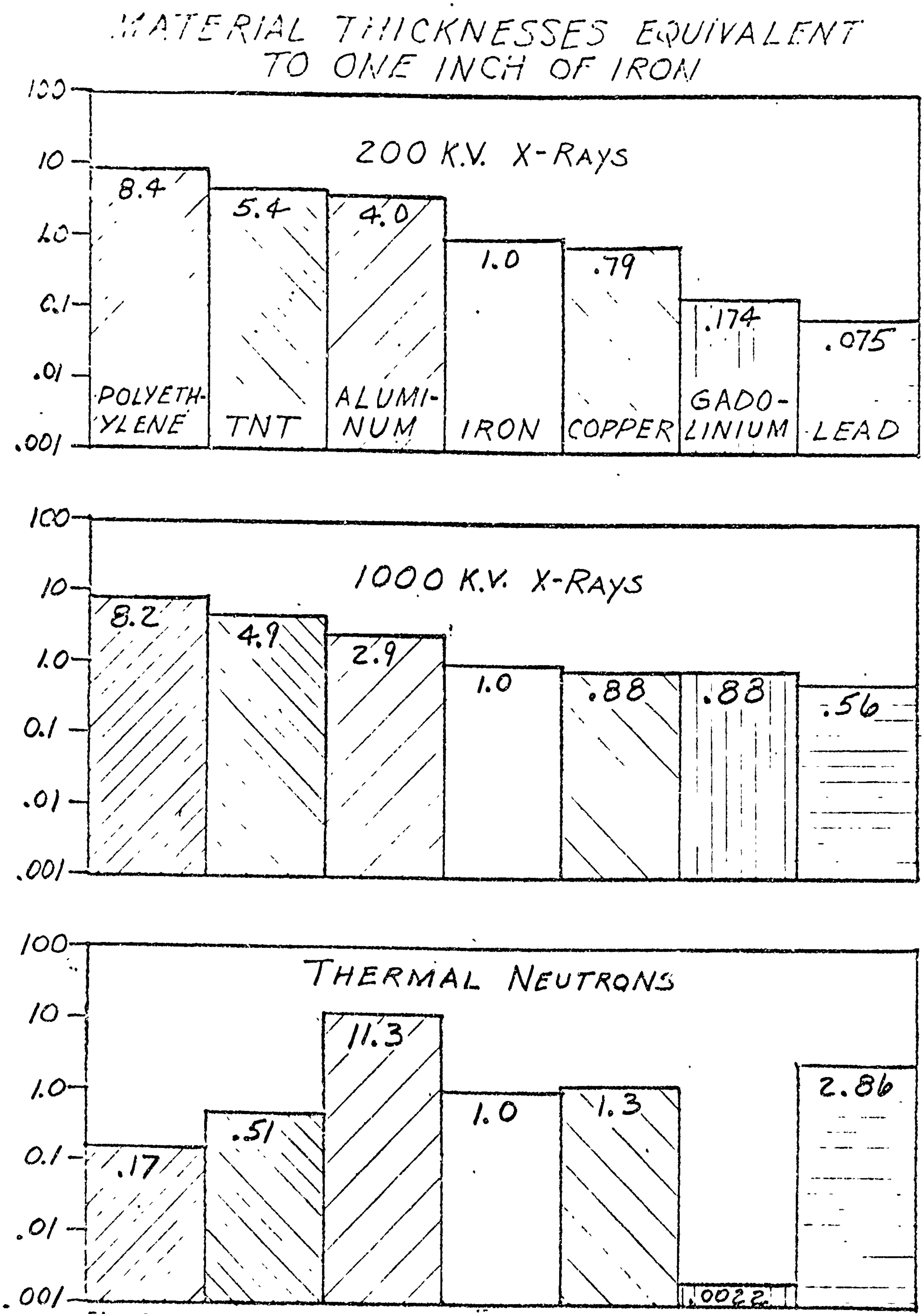
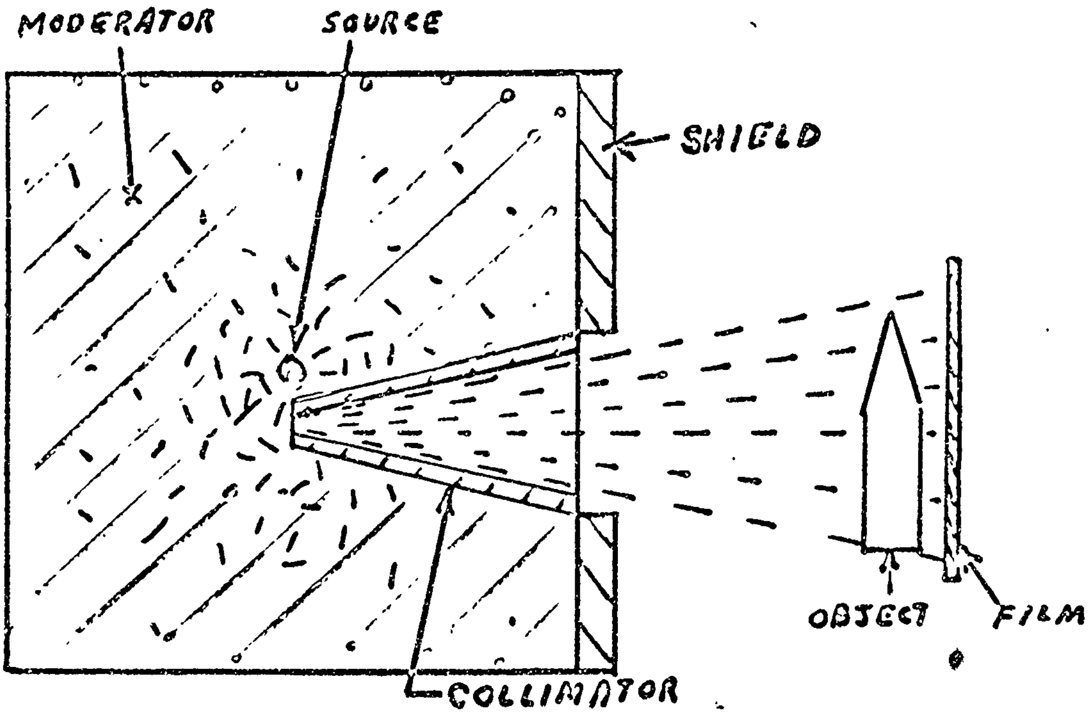

MATERIAL THICKNESSES EQUIVALENT
TO ONE INCH OF IRON
200 K.V. X-RAYS
8.4
5.4
4.0
1.0
.79
.174
.075
POLYETH-
YLENE
TNT
ALUMI-
NUM
IRON
COPPER
GADO-
LINIUM
LEAD
1000 K.V. X-RAYS
8.2
4.9
2.9
1.0
.88
.88
.56
THERMAL NEUTRONS
.17
.51
11.3
1.0
1.3
.0022
2.86
100
10
1.0
0.1
.01
.001

Fig. 11



SMALL SOURCE NEUTRON RADIOGRAPHY SYSTEM

Fig. 12

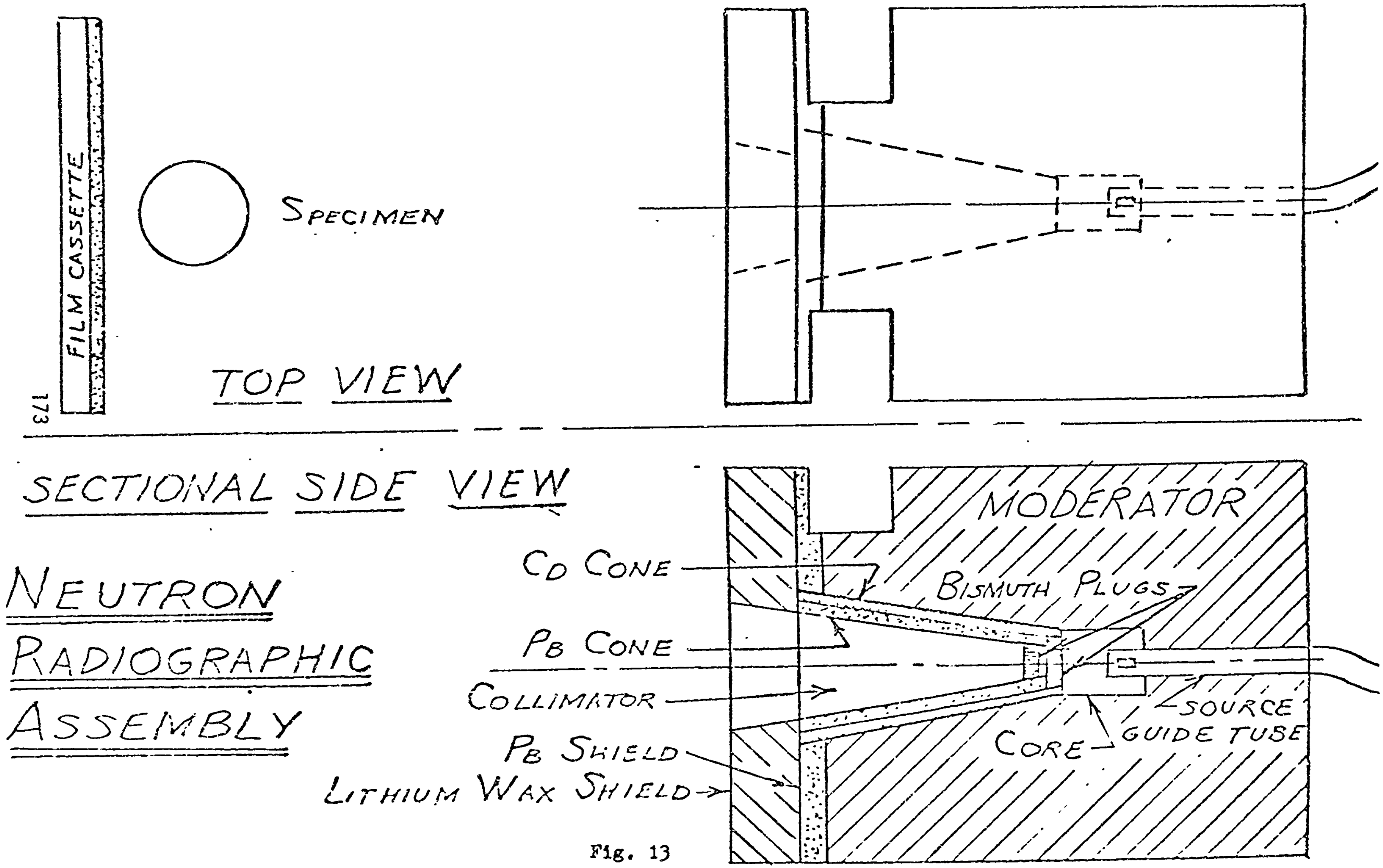

FILM CASSETTE
SPECIMEN
TOP VIEW
SECTIONAL SIDE VIEW
NEUTRON RADIOGRAPHIC ASSEMBLY
MODERATOR
CD CONE
BISMUTH PLUGS
PB CONE
COLLIMATOR
SOURCE GUIDE TUBE
CORE
PB SHIELD
LITHIUM WAX SHIELD

Fig. 13

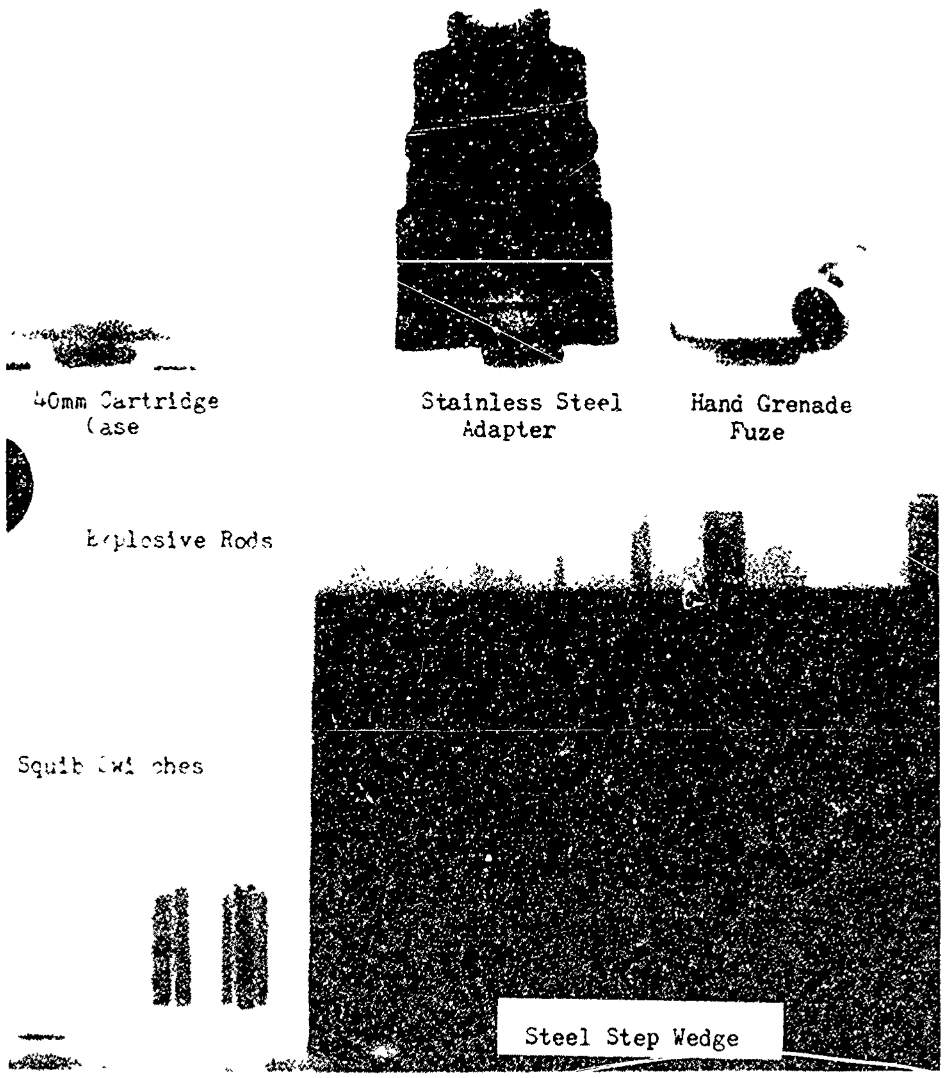


FIG. 15 Neutron Radiograph of Various Munitions Components and Test Specimens.

Full Partially Filled Empty

Full Partially Filled Empty

FIG. 16 X-ray (upper) and Neutron (lower) Radiographs of 40mm Cartridge Cases having various Levels of Propellant Powder.

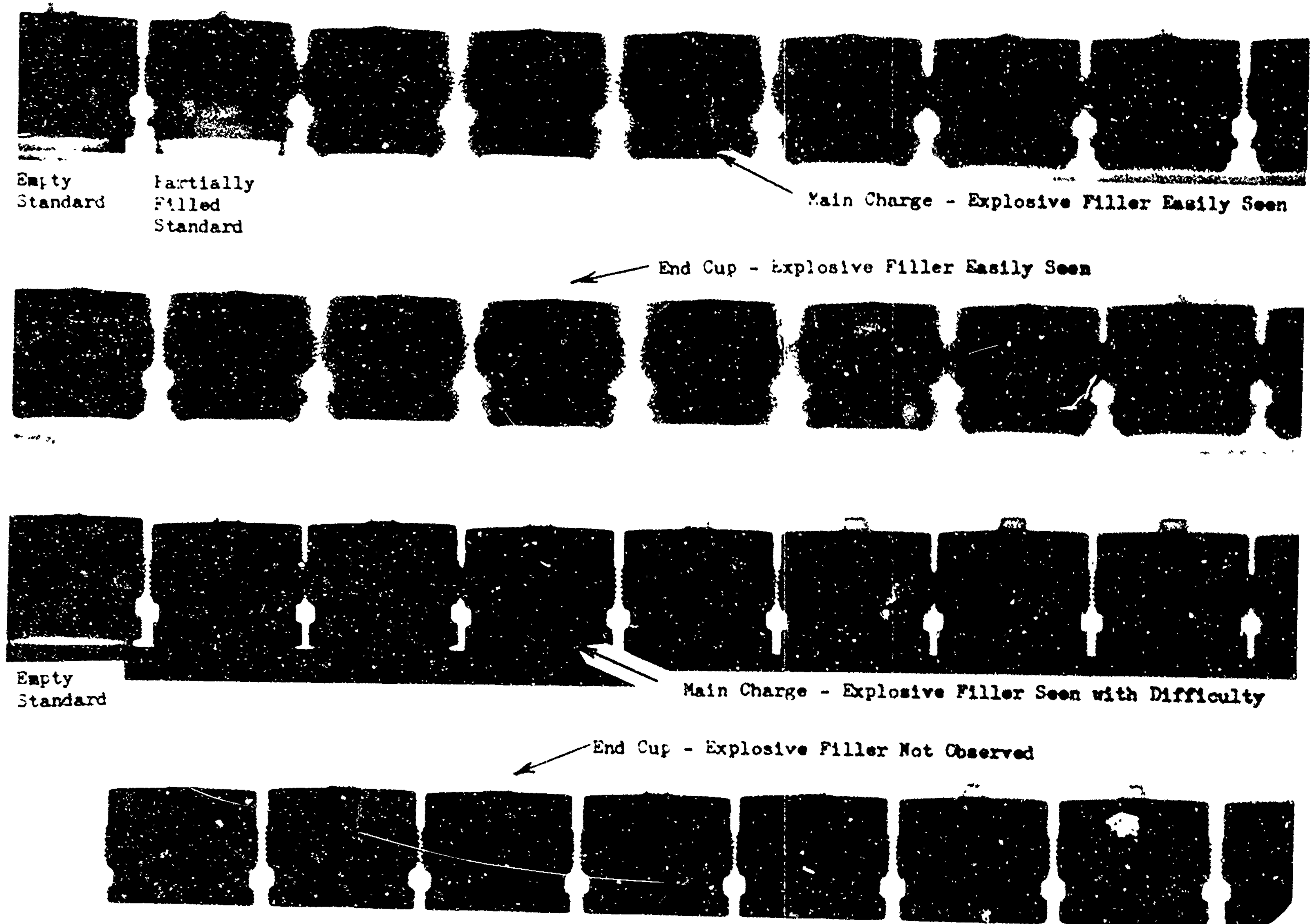


FIG. 17 Neutron (upper two rows) and X-ray (lower two rows) Radiographs of Booster Assemblies having Steel Cases and RDX Explosive Filler.

APPENDIX I - Description of Neutron Radiographs, Figures 15, 16, and 17.

Figure 15. The hand grenade fuze, adapter, cartridge case, and squib switches are all standard components of munitions items and were selected to demonstrate the ability of neutron radiography to show low density, organic materials inside metal enclosures. All of these items are routinely examined by x-ray radiography, but the neutron ir show distinct improvements in sensitivity in all cases. The ste tep wedge shown in figure 15 ranges from 1/4 to 1 1/2 inches thick in 1/4 inch increments. Clearly showing through the 1/4 inch step are four explosive (TNT) rods down to 1/32 inch in diameter. A fifth rod 1/64 inch in diameter is barely visible on the original radiograph. On the original, the 1/32 and 1/16 inch diameter TNT rods are detectable through the 1 inch step; the 1/8 and 1/4 inch rods can be seen through the 1 1/4 inch step. The same explosive rods were also exposed with step wedges of lead, aluminum, and brass, all of which showed the 1/64 inch rod through at least 1 inch of the metal. Munitions items are commonly constructed with these metals surrounding thin sections of explosive materials, and the ability to radiographically inspect the internal explosive is important to assuring their safety and reliability.

Figure 16. This compares x-ray (top) and neutron radiographs (bottom) of 40mm cartridge cases with respect to their ability to show the level of propellent powder within their propellent cups. Even on the original negatives, x-rays gave very poor images, and propellent level could only be seen by the most experienced film readers. The full, partially full, and empty conditions of the three cartridges are obvious on the neutron radiographs.

Figure 17. These steel cased, explosive boosters were x-rayed to assure presence of explosive filler in both the large inner cavity and the small cup on the end. The condition of the large cavity could be determined with difficulty, but no refinements in x-ray technique could show any difference between known full and known empty end cups. The neutron radiographs show the difference at a glance, and even small voids in the explosive can be observed.

PAPER NO. 7

FEASIBILITY OF DETERMINING TRACE AMOUNTS OF BORON IN TITANIUM USING THE NUCLEAR TRACK TECHNIQUE

Forrest C. Burns
Materials Sciences Division
Army Materials and Mechanics Research Center
Watertown, Massachusetts 02172

ABSTRACT

Conventional analytical techniques for determining microgram levels of boron in metals are subject to large errors and are very tedious and expensive.

In the case of titanium, it takes several days to slowly dissolve the sample so that no boron is lost.

By using the nuclear track technique, where the boron in titanium is subjected to thermal neutrons and the alpha particles from the nuclear reaction are recorded on cellulose acetate butyrate, a rapid and nondestructive boron analysis can be performed. The entire analysis takes only ten minutes. In addition to the analytical result, a pictorial representation of the boron distribution is also obtained.

This technique has a potential use to nondestructively analyze for trace amounts of boron in metals that do not yield interfering n-(alpha) reactions.

This paper presents the technique for the boron analysis and points out the specific advantages of the analysis over conventional methods.

INTRODUCTION

Even small concentrations of boron in titanium cause the formation of hard titanium boride precipitates which act as stress concentrators that reduce the strength and ductility of titanium. In order to detect this boron, samples of titanium must be dissolved and the boron determined colorimetrically. The dissolution process is long and tedious, and there is a great chance that some of the boron will be lost.

After reviewing the problem it was felt it might be possible to detect the boron using a nuclear technique. A literature search revealed that the nuclear track technique had been used to detect and analyze for boron in biological materials. From the information available it appeared feasible that the method could be used to analyze for boron in titanium.

DISCUSSION

The nuclear reaction $^{10}B(n,\alpha)\ Li^{7}$ has a very large total thermal neutron cross section of 3840 barns and therefore a high degree of sensitivity for boron detection.

When a boron atom captures a thermal neutron, an alpha particle of 1.47 MeV is emitted. When this alpha particle is captured in some suitable material such as a thin film of cellulose acetate butyrate one has a possible method for boron detection. It is known that high energy nuclear particles cause damage in certain organic substances. By examining the organic film the alpha tracks can be counted and related to the boron concentration and also boron distribution. The sample is not destroyed and can be used for further studies.

In order to enhance the detection process the film or detector is removed from the titanium sample and etched in hot NaOH solution. By judicious selection of temperature and etching time, a clear slide of the nuclear tracked plastic is obtained with the alpha tracks greatly enlarged so that they can easily be seen with a light microscope.

The etched detector is then mounted on a glass slide for examination with a microscope. At the same time that the sample is irradiated, a comparator with a known amount of boron is also irradiated so that both sample and comparator are exposed to the same thermal neutron flux. The comparator's detector is placed beside the sample's detector on the glass slide for convenience of examination.

The number of alpha tracks are counted on both detectors, and these values are compared in a linear relation to determine the amount of boron in the titanium sample.

It is also possible to calculate the number of tracks that can be produced by a given amount of boron by arbitrarily assuming that 40% of the emitted alpha particles are detected by the plastic:

$$T = \frac{0.4\ Nm\sigma F}{Mx\ 10^{24}}$$

where
- T = Number of alpha tracks
- M = Atomic weight of natural boron
- σ = Thermal cross section of natural boron for the n, α reaction (750 barns)
- F = Integrated thermal neutron flux

For example, using a reactor with a thermal neutron flux of 10^{13} neutrons/cm^2/sec and F is equal to 10^{13} neutrons/cm^2 for a /second irradiation, one picogram (10^{-12} gms) of boron will give 170 tracks. The sensitivity can be improved by increasing the duration of irradiation.

For very low boron concentrations one must be especially careful to see that the plastic detector is clean and free from artifacts. A trial run should be made with the detector alone in order to establish a background value for the detector. Tracks due to lithium, boron and possibly some n,α reactions on lightweight elements such as oxygen in the plastic matrix are possible. Some tracks are no more than artifacts such as scratches and voids of the same size and shape as an alpha track. Unless the boron concentration is below 1 ppm the artifacts present little difficulty in the analysis.

EXPERIMENTAL

Samples of a special titanium alloy (Ti-5Al-8V-2Sn-1Cu-1Fe-3Zr) approximately 0.5" by 0.375" with one smooth surface for mounting the detector were used for the boron analysis. The detector was pressed against the titanium surface using a small clamp and hot paraffin wax was placed around the edges with an eyedropper. After the paraffin cooled, it held the detector firmly in place. It is very important that the detector be as close as possible to the titanium in order to achieve maximum resolution and efficiency. A comparator with a known amount of boron (NBS 1098) stainless steel with a certificate analysis of 140 ppm boron was also prepared. Both sample and comparator were then simultaneously irradiated in the thermal neutron position of the NBS reactor for 3 seconds.

The detector was then carefully removed from the samples by breaking away the paraffin wax. It is important to record the exact orientation of the detector in relation to the samples. Otherwise a significant amount of information concerning the boron distribution in the titanium would be lost.

The detector slides are then etched in a beaker containing 6.5 N NaOH solution at 70°C for 8 minutes. A magnetic stirrer kept the

solution moving over the slides. The slides were next removed from the etchant and washed with water to remove the remaining NaOH.

The detector slides were then mounted on a glass microscope slide, side by side, so that their tracks could be counted and compared. The microscope was used at a power of 450. One hundred random fields measuring 0.042 mm x 0.050 mm were counted on each detector to achieve good statistics. Table I shows the random field counts for both sample and comparator. Fig. 1. shows that the boron distribution is definitely not uniform.

Table I. RANDOM FIELD COUNTS
Field Area: 0.042 mm x 0.050 mm
Samples: NBS 1098 S.S. and Titanium

Field	No. of Tracks S.S.	No. of Tracks Ti	Field	No. of Tracks S.S.	No. of Tracks Ti	Field	No. of Tracks S.S.	No. of Tracks Ti
1	30	38	46	8	26	90	14	6
2	28	13	47	9	12	91	5	2
3	0	2	48	47	10	92	37	4
4	30	49	9	9	13	93	9	16
5	99	70	50	20	35	94	110	28
6	25	14	51	20	8	95	20	6
7	89	24	52	20	2	96	75	3
8	14	7	53	39	10	97	48	3
9	21	2	54	3	4	98	10	32
10	20	71	55	57	8	99	27	14
11	32	8	56	10	5	100	50	15
12	10	42	57	41	2		2427	1470
13	12	9	58	19	5			
14	120	17	59	32	3			
15	22	14	60	33	2			
16	17	25	61	13	9			
17	6	4	62	6	10			
18	4	3	63	10	72			
19	10	8	64	17	5			
20	12	5	65	45	2			
21	32	14	66	22	14			
22	42	12	67	13	3			
23	14	17	68	26	13			
24	9	16	69	16	11			
25	7	8	70	17	3			
26	22	17	71	21	8			
27	24	11	72	24	1			
28	5	12	73	33	6			
29	24	9	74	31	47			
30	18	9	75	29	3			
31	46	7	76	16	6			
32	18	14	77	14	8			
33	11	25	78	23	56			
34	12	22	79	60	7			
35	12	27	80	26	7			
36	25	6	81	5	12			
37	10	20	82	27	25			
38	9	27	83	20	11			
39	20	6	84	10	4			
40	1	5	85	13	12			
41	13	4	86	45	4			
42	16	9	87	20	3			
43	13	1	88	18	13			
44	8	82	89	43	5			
45	8	30						

$\frac{1470}{2437} \times 140 \text{ ppm} =$

$.0577 \times 1470 = 85 \text{ ppm}$

CONCLUSION

By using an automatic counting device these analyses can be performed very rapidly and economically. The total analysis time being 10 - 30 minutes. This compared with the conventional method of analyzing for traces of boron in titanium of one week and the skills of a highly trained specialist show dramatically the advantages of this technique.

In addition to the quantitative chemical analysis a very good picture of the actual boron distribution is obtained. This data is very useful to the precision microscopist and the metallurgist.

From the standpoint of radioactivity, even if the sample itself got extremely radioactive this causes no problem since the detector is all that is of interest for the analysis and it is not highly radioactive.

Since the nuclear track technique is a surface phenomena there is no problem of neutron absorption due to the very high thermal cross section of boron.

The only impurities that can interfere with the analysis appear to be uranium and lithium. Therefore, there should be no reason why the technique could not be used to analyze for boron in other metal matrices besides titanium.

FORREST C. BURNS
Materials Sciences Division
Army Materials and Mechanics
Research Center
Watertown, Massachusetts 02172

PAPER #8

ULTRA-HIGH SPEED TESTING TECHNIQUES

ALBERT CHALFIN

US ARMY FRANKFORD ARSENAL

ABSTRACT

Frankford Arsenal is engaged in a Small Caliber Ammunition Modernization Program (SCAMP), which has as its objective the development of an automated high speed manufacturing process for fabrication of complete packaged rounds of small arms ammunition at rates of up to 1200 per minute. The manufacturing process requires a companion inspection system capable of performing 100% on-line discrimination of non-conforming material.

This paper describes the automatic inspection system to be used on a portion of the SCAMP; the case manufacturing sub-module. The inspection techniques described cover dynamic measurements, at these high speeds, relating to material characteristics and interior and exterior dimensions. Approximately 50 measurements of these characteristics must be accomplished during each 20 msec time interval. The paper also describes the computer approach used for control of data acquisition, data evaluation, and material ejection.

PAPER NO. 8

ULTRA-HIGH SPEED TESTING TECHNIQUES

Albert Chalfin
U. S. Army Frankford Arsenal

Frankford Arsenal is currently engaged in a high priority program directed toward the modernization of the Army's small caliber ammunition manufacture. This is being accomplished under the Small Caliber Ammunition Program (SCAMP) in two phases. The Module "A" phase covers all small caliber ammunition of the type used in individual weapons; that is, 5.56mm, 7.62mm, Cal. .30, and Cal. .30 Carbine. Module "B" includes larger calibers .50 cal., 20mm and 30mm, more commonly used in aircraft and aarmor applications.

The modernization objectives call for the development of a manufacturing system which will produce a continuous output of completed acceptable cartridges in excess of 1200/minute. To achieve these objectives, a large number of matually dependent project tasks have been established in the areas of manufacturing technology, material transfer, and production automation.

It is the purpose of this paper to describe the SCAMP inspection problem, discuss the systems approach being used in its solution, summarize briefly the current status of the program, and provide a more detailed view of some of the typical inspection tasks by describing one of the inspection systems under development.

The inspection program has as its objective, the development of an inspection-rejection system which will perform the requisite measurements and evaluations required to reject non- conforming ammunition components, as they are being manufactured by the SCAMP module.

The magnitude of the problem is best illustrated by the cartridge case sub-module, where cases are manufactured in excess of 1200 pieces per minute. Not only must numerous external and internal dimensional measurements be made on each piece with an accuracy of 1000th of an inch, but also material property, such as hardness and surface flaws, must be accurately determined.

This is a formidable inspection problem when conducted on a sampling basis, under the most favorable laboratory conditions. However, it is only when one remembers that these inspections must be performed in a factory environment, 100% on-line, while the cases are shaking, vibrating, hot from metal forming operations, wet from lubricants and moving in excess of 9 feet per second, that the true scope of the SCAMP problem emerges.

To meet and solve this inspection problem, a systems approach has been adopted, which considers the major aspects of the problem and coordinates the various specific efforts which are required to solve it.

The inspection systems approach being followed can be divided into seven major areas.

1. Process Requirements. One of the first tasks of the inspection effort is to define precisely the exact parameters which must be measured, as well as their specific tolerance. In some instances inspections have evolved by virtue of the manufacturing process now employed. With the radical revisions brought about by SCAMP, significant inspection changes must be made. For example, the reduction of the current three draw process for case manufacture, to a two draw process permits intermediate inspections to be eliminated. In one type of case sub-module, proper intermediate manufacturing processes are monitored by measuring tool forces rather than inspecting the work piece. In some cases, current inspections are still required, but the specific parameter measured may be changed, as in the possible substitution of 100% on-line cup hardness measurements for sampled materiel grain size determination. In every instance, a careful evaluation must be made of the current inspection requirement to define its exact applicability to the SCAMP process. This study is currently under way and will continue for the life of the SCAMP development, to permit solution of the inspection problems and to insure that full advantage can be taken of instrumentation improvements, as they occur.

2. Work Piece Conditions. Another major effort in the inspection process determination, concerns itself with the work piece conditions at the time of inspection. Not only are the inspections themselves to be precisely defined, but also the location in the manufacturing process which is optimum for the inspection system. As has been pointed out previously, the fact that the pieces to be inspected are neither fixed or clean, must be considered. In addition, the specific orientation of the work piece must be considered in order that a proper interface between the piece and the inspection material being used, can be effected. It is highly desirable that the inspection system for the various parameters to be measured, be located so as to take advantage of natural orientation. Where this cannot be done, orienting mechanisms must be introduced.

3. Inspection Techniques. Because of the high rate of manufacture in the SCAMP module, it is apparent that conventional contacting inspection devices will provide, at best, only marginal reliability and performance. The problem of inspection gage wear and moving part inertia poses almost insurmountable problems for the contact type of inspection material. For this reason, the major effort on this portion of the systems approach has been in the development and acquisition of non-contact type inspection materiel which can be utilized at the speed required. In general, the inspection required can be divided into three major categories:

a. External Dimension

b. Internal Dimension

c. Material Property

Later in the paper we will describe specific inspection techniques which are currently under development in each of these areas. The application of any of these techniques to a required inspection is a function of the work piece orientation, the interface conditions, and the accuracy required. A major current effort is concentrating on the techniques themselves. We are attempting to categorize the applicability, limitations, and special considerations which must be recognized before these techniques can be applied to specific inspection problems.

4. System Automation. It is clear from an analysis of the number of pieces being manufactured and the large number of inspections which must be made on each, that in order for the system to be feasible, it must provide the capability for the high-speed data acquisition and data evaluation which is required. In most cases, the inspection will be performed at a point which is physically removed from the actual rejection station. This separation of the rejection and evaluation functions makes mandatory a sophisticated control system for the process. Clearly, the system must be highly automated and under the control of a computer. Real-time computer operating systems have been evaluated which provide the requisite speed and data handling capabilities, foreseen as necessary for the various sub-modules. In addition, the operator interface with the system must be considered in the definition of the automated system which to be developed. Timing studies for the process of inspection are underway for the first of the sub-modules, the case sub-module. For this sub-module a major computer cycle of 41 milliseconds has been established, which provides for all of the required inspections to be performed and evaluated for a single case. It is currently estimated that there will be approximately 50 inspections conducted on each case, thus resulting in a minor computing cycle of 800 microseconds for each measurement.

The inspection program functions, e.g., Data Acquisition, Data Evaluation, Calibration, Ejection, Display, etc., must be performed for each of the measurements which are taken. Each of these will be performed by the computer system within the 800 microsecond time slice which is allocated for the specific measurement. While these functions may seem extensive, they are well within the capability of the modern minicomputer with a 750 nanosecond memory system.

5. System Performance. In order to develop an effective practical operating inspection system, the major system performance

parameters must be addressed. If the problems associated with these parameters cannot be solved, then a vaiable system cannot be developed. Such system parameters as frequency, accuracy, time intervals, and difficulty of calibration, must be carefully determined. A method must also be provided for on-line verification of the inspection system performance. No matter how exotic an inspection technique is employed, if it is malfunctioning, and the operator has no way of knowing it, then the system is useless. We will describe a technique for using radioactively tagged calibrated work pieces to assure that the inspection system is operating and provide for an automatic self-verification by the computer system. Another important aspect of the system performance concerns the specific maintenance requirements and provisions which are developed, in view of the complex nature of the automated control system as well as the sophisticated inspection techniques used and the factory environment in which the system will live.

6. Standardization. Since the SCAMP module is comprised of a number of sub-modules, all of which must incorporate inspection systems, it is imperative that a high-degree of standarization between the modules and their inspection systems be obtained in order that an economically feasible system is developed. It is intended that as inspection techniques are developed, they will be applied in all of the sub-modules, so that standard transducers, interface systems, and orient mechanisms can be used wherever possible. It is anticipated that the same computer system will be employed for each of the sub-modules whose inspection systems warrant the computer application. The standard interface, thus employed, will facilitate the eventual tying together of all these systems so that the data being acquired can be fed to an automated process controlled system to provide for automated quality assurance. This process quality control system is currently under a contract definition study.

7. Laboratory Test Facility. Since it is not intended to reinvent the wheel in this program, a large portion of the effort consists of evaluating existing techniques and instrumentation currently available for commercial vendors. However, it has been our experience that there is a significant gap between the promised performance of such equipment and the actual performance which can be attained. Since the measurement application and system being evolved here is new, much of the equipment now available has never been applied in similar situations. For this reason, the SCAMP program has provided a laboratory test facility to permit the test and evaluation of these various commercially available instrumentation. In addition, the SCAMP laboratory facility provides the technical workshop where new inspection techniques may be developed and tested.

Case Submodule Inspection System

To illustrate the inspection approach being followed, the paper will describe the automated inspection system being developed for one of the SCAMP sub-modules. This submodule is the cartridge case sub-module under development by Waterbury-Farrel.

Figure #1 shows a block diagram of the inspection system, overlayed on a functional schematic of the Waterbury-Farrel Case Sub-module. With regard to measurement groupings, it was determined that three natural clusters of instrumentation would conveniently comprise three measurement/ejection stations. Those sensors concerned with cup data, those concerned with interdraw anneal, and those measuring final piece characteristics can be conveniently grouped in three stations, called Measurement/Ejection Stations 1, 2, and 3 respectively (M/ES-1, M/ES-2, and M/ES-3). Each station has but a single ejection device, activated by signals from the process control computer located in a fourth physical entity referred to as the Automatic Measurement Control (AMC). The peak production rates of 1440 pieces/min are indicated. The average production rates, however,are estimated at 1200 pieces/min.

The inspection requirements which have been tentatively established for each of the Measurement/Ejection Stations is as follows:

M/ES-1 — Cup Characteristics per Dwg. #B10542547

Outside Diameter--0.550", +0, -0.006

Wall Thickness--0.083", +0, -0.010 @0.105 above bottom inside surface

Wall Thickness Variation--not more than 0.005"

Bottom Thickness--0.140", +0, -0.007 on centerline

Hardness (Grain Size)--Rockwell F52-66

Weight-- 114 grains, +0, -6

M/ES-2 — Interdraw Anneal (after 2nd draw)

Hardness (Grain Size)--Rockwell B40-50

M/ES-3 Case Characteristics per Dwg. #C10524200

Case Length, finished:
1.760", +0, -0.010

Case length, head to shoulder
(non-critical):
1.4380"

*Headspace (head to gas seal-crtical):
1.500", +0, -0.006

Head diameter, outside:
0.378", +0, -0.007

Head diameter, beveled:
0.3325", +0, -0.007

Head bevel:
45 + or - 30'

Head thickness to extractor groove:
0.045", +0, -0.007

Groove diameter:
0.3325", +0, -0.0070

Groove width at 0.3325" diameter:
0.030", +0.005, -0

Groove width, total:
0.118", +0.004, -0

Groove bevel:
25 + or - 30'

Primer recess diameter:
0.1738", +0.0007, -0

Primer recess depth:
0.118", +0.004, -0

Case mouth, inside diameter:
0.2230", +0.0007, -0

Case diameter taper, extractor
groove to shoulder:
0.1746" per inch

*Dimension from head to a datum line on the shoulder at 0.3017"

basic diameter.

Case-wall thickness - Basic lengths for case-wall thickness tests; test-point lengths are measured from a reference point at 0.2000", +0, -0.050 from the case head.

Basic Length	Wall Thickness
0.335"	0.0165" min.
0.710"	0.0105" min.
1.100"	0.0075" min.
case mouth	0.0125", +0, -0.0020

Hardness Gradient

Vent Hole Presence

Cartridge Case Flaws per MIL-STD-636

Measurement Techniques

Quite a number of candidate measurement techniques were examined for their potential usefulness to the high-speed, high-precision application described here. The need for accurate, repeatable measurements at these rates practically eliminates serious consideration of most contacting-type gages. Most of the promising techniques couple the sensor to the workpiece with some form of electomagnetic radiation, measuring the change in circuit parameters and correlating these with know characteristics of the piece under measurement. The following discussion covers the major measurement techniques upon which Waterbury-Farrel Cartridge Case Submodule Inspection system is being developed.

Hardness Measurement. Industry has for years been sorting such items as ball bearings and nuts and bolts at fairly high-speeds by means of eddy-current devices. The parts are passed rapidly through the field of a probe coil which is carrying an alternating current. A second coil, usually coaxial with the first, will have greater or lesser voltages induced in it depending on the coupling provided by the objects passing through. The conductivity of the metallic parts, being a function of the molecular structural arrangements existing within the material, is thus related to a signal voltage. A standard reference part is placed within a second identical set of coils, and the differential signal amplified and displayed on a scope, or utilized to operate threshold detection devices and to actuate relays for defective part ejection.

The questions arise regarding precision of differentiation between specimens of only slightly differing hardness, and of shielding the sensitive portions of the probe coils from extraneous fields which may exist in the measurement environment. The design parameters available to solve such applications problems include coil size and shape (whether they envelop the piece or probe it as it passes by), frequency, phase angle, and gain. Thus for the sorting of annealed from hard 2nd draw pieces in M/ES-2, which may differ by 40 to 45 Rockwell B numbers, and enveloping coil and relatively low sensitivity suffices. For the more exacting task of inspecting incoming cups for conformance to drawing tolerances on grain size, probes with relatively high sensitivity and additional shielding are selected. The most difficult hardness assessment on the cartridge case is the hardness gradient on the finished case, which will require several specially wound small coils and a high degree of both sensitivity and of shielding from extraneous fields. Figure 2 shows a SCAMP Laboratory test of an eddy current technique to discriminate between hard and soft test specimen as they move through a sensing coil. Successful test runs have been made at speeds of an excess of 1400 per minute. The plastic tube contains a number of test pieces in a recurring pattern. As the cases pass through the coil, the instrument detects the threshold signals and provides an indication to a mini-computer, which records the system performance.

A minicomputer provides a printer record of the number and types of errors. In a 25-hour continuous run, the system shown here, successfully separated annealed and non-annealed first draw cups with only one error in 1,900,000 cups.

Dimensional Measurements by Optics. Dimensions such as the outside diameter of the cup, and the depth and diameter of the primer pocket in the finished case, will be measured utilizing a ranging optical probe, a new non-contacting surface sensor with claimed capability of measuring a wide variety of surfaces, ranging from dull-diffuse to highly reflective, to accuracies better than 10 microinches contacting probes. Four infrared beams 90 degrees apart are emitted by solid state devices and focused approximately 3/4 inches from the end of the probe body by a precision ground lens. Receptors in the body of the probe monitor the energy reflected from the surface and convert the intensity into three bipolar d.c. output signals, one for range and two for normality (tilt) in two planes. The range output is linear over a short region near focus, permitting the probe to be used as a nulling device. The null indication represents the contact of the focal point with the surface, as if an extension of the probe.

The normality outputs in two axes provide relative attitude information of the probe with respect to a given surface. When the probe axis is at 90 degrees to the axis of the surface being measured, the readout indicates a null position. Because of the high sensitivity of the receptors, even the slightest deviation will cause either a positive or negative output, depending on which quadrant is affected.

The probe's nulling capability results in highly accurate measurements of surface position. (accuracy of the order of 100 microinches has been achieved with developmental materiel). This permits the device to discriminate between two opaque or transparent surfaces positioned very close to one another. By moving the probe with respect to these surfaces, the probe's output can provide a means for obtaining a differential measurement of their displacement.

While the linearity of output signals in the null region permits measurement of small deviations an alternative approach may be employed which substantially increases the range of measurement. A fully automatic operation would utilize all three signals. The normality signals would continuously control rotational servos to maintain the probe normal to the surface. The ranging signal would control the X and Y or Z servos to move the machine arm; such applications suggest themselves for reading intricate contours. Readout of the linear encoders in X and Y or Z could be interlocked so that readings are recorded only when the ranging signal reaches null.

The device under evaluation for optical dimensional sensing is a Ranging Optical Probe packaged in the form of a cylinder 1-5/8 inches in diameter by 6 inches long.

Weight Measurementsby Force-Balance Servo. As part of the incoming cup inspection it is vital to establish that the cup has sufficient mass of metal to undergo the subsequent forming operations successfully. It is proposed to employ a rapid response servo scale to make this measurement.

The electromagnetic scale was originally designed specifically to weigh the 40 grain M193 Ball Bullet to an accuracy of 0.25% and at a minimum rate of 20 per second. The mechanical and electrical margins are sufficient, however, to permit adaptation to measurement of the 114 grain 5.56mm cartridge case cup. The major requirement for adaptation is an increase in the diameter of the scale pan to accommodate the larger diameter. The mechanical assembly consists of a moving parallelogram linkage of thin wall stainless steel tubing interconnected by flexure pivots. The upper beam is rigidly attached to the rotor of a brushless DC torque motor. A vertical link supports the weighing pan at its center and connects the upper beam to the lower beam. Both upper and lower beams are suspended on fixed supports with flexure pivots. The moving plate of a capacitive position sensor is mounted on the uppper beam opposite the weighing pan. The electronic servo amplifier is mounted on the aluminum bottom plate next to the position sensor, and the entire unit is encased in an aluminum cover plate. The moment of inertia of the moving parts is about 0.0004 in lb/sec2, the torsional spring rate of the eight flexures is 0.44 in lb/rad, and the measured minimum natural frequency of the scale is about 750 cps.

To balance the unknown weight, the scale uses an electromagnetic limited-rotation, permanent magnet motor commonly known as a torque motor. Due to the action of the servo feedback, this motor exerts a torque on the moving elements which equals the torque introduced by the unknown weight. When the scale is unloaded the position sensor senses a null or zero position. When the scale pan is loaded, the input to the scale is a distrubrance torque due to the unknown weight. This disturbance cases a momentary shift from the zero position. The position sensor thereupon generates an error voltage which is amplified and applied to the torque motor, which, in turn, generates an opposing torque that drives the scale back to essentially its zero position. At this point the coil current is proportional to the weight applied to the scale.

The output of the scale is the voltage across a small resistance inserted in series with the torque motor coil. Since this voltage is proportional to the coil current, it is a very accurate measure of the unknown weight. The scale as designed can respond to a step function weight load of 0.25% in 0.013 seconds.

The servo-balanced scale to be used was developed for Frankford Arsenal by Engineering-Physics Co., Rockville, Md., and will be modified as described to accept the cartridge case cup.

Dimensional Measurement by Ultrasonics. An excellent means of determining thickness of metallic parts at high speed is provided by the device known as an Ultrasonic Micrometer. The Ultrasonic Micrometer is a high-speed pulse echo thickness gage that makes precision non-contacting measurements on materials such as tubing, pre-draw cups. and screw machine parts, while the object is in high-speed motion. Measurements and decisions can be made at a rate over 1200 per second. The instrument provides complete gaging of diameter, out of round, wall thickness, and eccentricity.

Dimensional changes in the part are detected by measuring distances from either the transducer to the part, or between the front and back surfaces of the part. Ultrasound is conducted to the part via a high velocity 1/8 inch diameter liquid stream. Alternatively, the part and transducer can be totally immersed in the liquid, commonly water. Diameter variations from part to part are measured by the distance of part surface on nearest approach to the transducer. The minimum wall thickness that can be read is 0.015 inches, and the full-scale of the instrument covers 0.1 inches. This can be offset so that the instrument is indicating the last 0.1 inches of a part having a thickness up to 1.0 inches.

Both diameter and thickness are gaged simultaneously. Outputs for external relays or solenoids are provided for both measurements. Each alarm output has a high voltage transistor that can be used in the normally open or normally closed condition. The switched transistor outputs will operate on diameter or thickness changes of only 0.001 inches. Stability of measurement and alarm settings is 1% over a temperature range of 0 C to 50 C.

Profile Measurements by Optics. If a complete profile of the case as it emerges from the submodule can be sensed, it will contain information regarding all external dimensions, tapers, and contours which determine quality of the product. Several types of contour devices are presently under evaluation. These fall primarily into two categories, those using high density diode matrices, and those employing photomultiplier tubes.

Thus far, the major laboratory effort has been concentrated on the latter type. In this type a special photomultiplier tube positioned to observe object moving by illuminated in silhouette is utilized to measure across the two light-dark boundaries of the piece, providing a dimensional reading as the time difference from one to another, and utilizing the forward motion of the object to provide scanning. The result is a dimensional silhouette of the passing object.

The optical head senses the position of the target. It contains an image dissector tube which forms the target image obtained from the lens system. The tube converts observed transits of the light-dark boundaries into electron analogs. An electromagnetic deflection yoke positioned over the tube envelope deflects the electron beam formed within the photomultiplier; the deflection drive current is proportional to object width. The design permits the optical head to remain stationary.

The optical head is positioned for optimum viewing, and a lens appropriate to the working distance and field of view is selected. A reflex viewer that is part of the lens system is used to focus the target on the photo tube and assure a clear unobstructed field. The optical head assembly is cylindrical, so it may easily be rotated to adjust the tracking axis for motion which is neither vertical nor horizontal. A circular scale marked in degrees of arc on the rear of the tracking head permits an accurate position setting to be made.

There are two possible interfaces, light over dark and dark over light. As a consequence there must be a means of changing the phase of the current to the deflection yoike as the object interface moves across the aperture. The servo circuitry is designed to perform this switching function. When it is placed in the mode for determining width-dimensional differences, multiplex circuitry switches the tracker back and forth between edges of the object. Hold ampliers in the servo loop remember the last target position as voltage level.

The deflection amplifier is switched between two hold amplifiers. The time for the beam to swing from one edge to the other is a function of the slew rate, approximately 3 microseconds. Two data-hold amplifiers are alternatively connected to the coil current, and this permits the position of each edge to be determined. Switching of the data amplifier is delayed approximately 5 microseconds to allow for the slew time. The most serious deficiency of the photomultiplier profile approach stems from the relatively low resolution, due to the current spot size of 050". Efforts are currently underway to reduce this size to less than .007.

The photo diode array employs a simular optical arrangement. Using electronic scanning, the diode array serves to provide the functions of the photomultiplier tube. It is possible to obtain photo diode arrays on .006" centers. With optical magnification of 12, an accuracy of .001" is theoretically possible. This type of unit is being obtained for evalutation in the SCAMP Laboratory.

Radioactive Tagging and Scintillation Detection. In order to assure that the inspection data acquisition system is

always in calibration, many types of circuit self-checks will be incorporated. For the actual transducer portion, however, it will be necessary to have pieces of known characteristics available at a moment's notice, to be run past the sensing heads. These pieces form the test lot for each station; they must be carefully measured and indelibly tagged so that their identify is never lost, and so that they may be recoved after passing through the station and before entering the next fabrication operation.

Many methods of tagging have been considered, such as paint, dye, plating, engraving, and scribing. None of these has the inherent attractiveness of radioactive tagging, however, since all of the others change the surface of the workpiece in some manner. The type of radioactive tagging selected does not affect the exterior of the part in any way.

The principle employed is to create neutron reactions in the molecules of the constituent materials, resulting in radioisotopes of relatively long half-lives and acceptable activity levels, which are sufficient for relaible detection by scintillation counters monitoring the parts emerging from the measurement/ejection station.

Neutron reactions of acceptable strength can be obtained in commercial and government nuclear reactors currently in operation. The important isotope is zinc-65, which has a half-life of approximately 250 days. The principal emission is a 1.1 Mev. gamma. The other zinc isotopes and those of copper are of higher activity but fortunately, with half-lives measured in minutes or hours.

The principle of radioactive tagging and scintillation detector monitoring of high-speed production lines has been successfully demonstrated using off-the-shelf commercial equipment in the laboratory of the SCAMP program at Frankford Arsenal. A view of the experimental apparatus is given in Figure 4.

Surface Flaw Detection. Several techniques are under development to be used in the on-line detection of case surface flaws at the required output rate.

A fiber optic, photo diode technique has been developed for Frankford Arsenal by FMC Corporation. In the prototype, the cases are brought automatically onto a rotating spindle. The spindle moves the test specimen in front of a large array of fiber optics, (110 Segments), which are connected to a photo diode sensor linear array. The test specimen is illuminated by a bright light source and the reflected images are sensed by the photo diodes. When a surface flaw is present, the intensity of the image is affected in a specific fiber bundle and the resultant change in signal strength from the photo diode is sensed and detected by electronic threshold detectors.

The existing equipment provides only six spindles. The full complement of 24 spindles will be installed and additional testing of the system conducted. The results obtained from this technique show an undesirable sensitivity to ambient light and surface finishes. In addition, the system is difficult to calibrate. Other techniques under study appear to be more suitable for surface flaw detection.

Another type of case flaw detect mechanism is now under development at Battelle Pacific Northwest Laboratories. This flaw detection technique makes use of a reflected laser beam which is projected on the specimen slightly above the center of its axis. The light is then reflected to a special mased detector array. If the laser light, which is coherent, is reflected to other than the masked areas, a signal is generated which permits the case to be ejected. This device is under development and will be brought to the laboratories for final evalaution and test in 1971.

Combined Measurements. While it has been possible to touch briefly only on the most important aspects of the major inspection techniques to be used, one additional item is worth noting. This is that each technique, the measurement evaluation will be accomplished in the Automatic Measurement Controller. For this reason, it is possible to evaluate several measurements to derive a third. For example, to obtain the case mouth I.D. measurement, the mouth O.D. and neck thickness measurements are utilized. Simularly, to obtain pocket diameter, the hole edge measurement is evaluated in conjunction with the speed of the piece being measured.

System Configuration

The automatic inspection system for the Waterbury-Farrel Case Submodule utilizes an Automatic Measurement Controller (AMC) to receive process information, make decisions and provide the requisite operator interface. Utilizing a small digital computer system, the AMC provides the following functions:

Receive, condition, and process measurement signals.

Display operational data to operator.

Provide operator controls.

Provide limit comparisons and programmed decisions on measurement parameters based on received information.

Transmit decision information to other modules of the system.

Provide self-testing programs for the system.

Provide printed record of performance.

Control ejection of non-conforming material.

A functional diagram of the AMC is shown in Figure 5. The computer portion of the AMC is the central storage area for dimensional limit information, data acquisition control, the processing of inspection data, and the location of the decision making capability. The digital output provides the accept or reject signals. A 20 microsecond multiplexer-A/D link provides for acquisition of data from any one of 128 measurement devices. The computer interrupt link permits burst data acquisition from measurement devices which provide continuous data. The digital output interface of the AMC provides for control of the measurement interface, by the computer, for measurement data synchronization. A teletypewriter is included for operator input and hard copy output of summary system performance data.

The electronics interface provides for the appropriate signal conditioning and measurement strobing which may be necessary.

The measurement devices fall into two categories: those which make a single measurement on the case being tested, and those which make a number of the same type of measurements on a single case. An example of the former would be a weight measurement. An example of the latter would be the case profile measurements.

Each of the single value measurement devices will be interfaced with the AMC in a similar manner. This typical interface is shown functionally in Figure 6. As the case passes the specific measurement transducer, the electrical analog of the measurement is generated. When the analog has been fully created, a strobe signal, either from the piece position or the transducer itself (if it is of the self strobing type), transfers the analog signal to a sample and hold amplifier. The interface then generates a measurement ready digital signal for the AMC.

The measurement value is retained in the hold amplifier until the AMC resets the interface via the appropriate digital output.

For the continuous measurement transducers, the AMC is signaled via the computer interrupt lines to acquire data in the high speed input mode on the appropriate multiplexer line.

In order for the AMC to accommodate the measurement devices, a special executive task schedule is used to service each in turn. To assume that the requisite speed can be handled, a major computing cycle of approximately 41 milliseconds has been established. This corresponds to 1440 cases/minute. During each major computing cycle all of the scheduled tasks are serviced. Based on an estimate of approximately 50 measurement devices for the Waterbury-Farrel Case Submodule Inspection System, a minor computing cycle of approximately 800 microseconds is created. The minor computing cycle is the time allowed for completion of a single scheduled task. Durihg the minor cycle, the following functions are accomplished by the stored program:

New Data Determination

Application of Calibration Function

Parameter Determination

Limit Application

Hardware Verification Test

Reject Bookkeeping

Ejection Function

Ejection Verification

Trend Analysis

Display Update

Utilizing a one microsecond cycle time computer, the minor cycle time provides approximately 400 instructions in the task program budget.

The proposed system configuration for Measurement/ Ejection Station No. 1 is shown in Figure 7. Bulk shipments of cartridge case cups enter the station from the floor hopper of a straight-line vibratory feeder. An elevator lifts the cups to the entrance of the orienting section at a rate several times faster than the maximum throughput requirement of 1440 per minute; the excess cups are returned to the hopper. Those cups traversing the orienting section properly, are fed into two tracks, mouth down, which feed twin leadscrews; those which are not correctly oriented are returned to the hopper. The leadscrews propel the cups through a series of sensors, spaced apart sufficiently to insure non-interference. The leadscrews are made from nylon t prevent interference with the eddy-current hardness measurements. Measurements in order of their position along the leadscrew are:

hardness - eddy current - sliding

outside diameter - infrared probe - sliding

weight - servo balance scale - momentarily stationary

wall thickness & variation - ultrasonic probe - array rolling

base thickness - ultrasonic probe - rolling

Sliding motion along the guide is changed to rolling motion by the addition of a thin lining of rubber on the guide track. A counter is provided to inform the control computer in AMC of the location of workpieces. Means are provided, by use of an auxiliary track, to introduce radioactively marked defective cups into the leadscrew transport mechanism as required to test sensor performance under dynamic conditions. An ejection gate, ahead of the main ejection gate, is provided to catch these radioactive specimens and remove them from the flow before they progress beyond the station and become lost. These radioactively marked cups are retained and re-cycled, being available to the operator whenever a question of sensor operation arises, or at the scheduled checkout times. The sensor which detects the presence of a marked cup is a scintillation detector installed in the line just before the radioactive cup ejector. The information that a marked defective piece has passed through, along with the sensor information concerning that piece, is the basis for a decision by the AMC computer as to whether that particular sensing device is performing properly or whether it may need calibration or replacement. The main ejection gate is just beyond. It is actuated only on signals from the AMC computer which reflect the total measurement history of each workpiece from the time it crosses the portal of the measurement/ejection station until it reaches the ejection gate. Only an impeccable record will allow the piece to pass this point; any out-of-tolerance condition on any of the dimensions being checked will reject it. Those cups passing this point are carried by the leadscrew into a storage hopper, from which at some later time they will be picked up and fed into the Waterbury-Farrel fabrication process.

The interface definition for such a station is minimized by the centralized configuration. Hopper to hopper transport requires only that the levels be monitored, and relative speeds between the measurement/ejection station and the fabrication line adjusted to suit. Also, the physical location requirements can be relaxed by installing short lengths of conveyor between exit points and the entry to the next segment of the line.

The proposed system configuration for Measurement/ Ejection Station No. 2 is shown in Figure 8. This station operates at the point in the line where 2nd draw workpieces have passed through the anneal, pickle, and wash, and also picks up its input material from the floor hopper of a straight-line vibratory feeder. This unit is basically similar to the one used for cups, but its orienting section is configured to operate with the more elongated 2nd draw shape. An elevator lifts the pieces previously deposited into the floor hopper to the entrance of the orienting section, again at a rate much higher than will ever be used, so that the orientor is kept saturated. Excess workpieces are returned for re-cycling. Properly oriented 2nd draw pieces are fed from the curved output track of the orientor-feeder onto a transport belt at a maximum rate of 1440 per minute. The belt carries each piece in turn through the eddy-current hardness sensor, which is the only measurement planned to be made at this point in the fabrication cycle. A counter keeps track of each piece's whereabouts, and a scintillation counter just beyond will catch any radioactively marked material passing this sensor; as in M/ES-1, it activates the radioactive material ejector to save the marked defective lot of parts from passing beyond the station. Beyond the radioactive materiel ejector is the eject gate which eliminates from the flow any piece which fails the eddy-current hardness test. Finally, an extraction wheel removes the good material from the end of the transport belt and drops it into a hopper from which it will continue its fabrication processing.

The M/ES-2 station configuration is similar in concept to that of M/ES-1, embodying the same hopper to hopper transport to ease the problems of interface definition and physical location.

The proposed system configuration for Measurement/Ejection Station No. 3 is shown in Figure 9. This station is placed at the output end of the cartridge case production submodule, to examine the finished product for all of the attributes and measurements which are established as determining acceptable quality. Since the possibility exists that the entire submodule may be operating simultaneously, the M/ES-3 must be capable of a top speed of 1440 cases per minute. The finished cases come out of the submodule mount down, and are first removed from the output conveyor belt and re-oriented so that they are travelling mouth-forward through a guide tube, impelled each by a separate lug projecting upward from a

continuous flat belt. In this manner, the cases are transported past an optical profile sensor, an eddy current hardness gradient sensor, and a laser beam optical flaw detector. At the end of the guide tube the cases drop into a rotary turret, rotating counter-clockwise as viewed from above, which carries them in succession past the optical vent-hole presence sensor, separate infrared probes which measure primer pocket depth and diameter, and a battery of ultrasoinc probes which sense wall thickness and wall thickness variation. A scintillation counter scans the line for radioactive test pieces, as before, which again are introduced at the operator's volition depending on operating conditions. The radioactive workpieces are separated out of the stream by the radioactive case eject gate, any defective cases out of the defective case eject gate, and good material exists through a final gate, out of the turret and into tubes which convey the material to its next destination. Each gate operates by means of a pneumatic impulse from a computer-operated solevoid valve, timed so that the trajectory determined by the tangential velocity and the air impingement deposit the workpiece into the mouth of the proper tube.

The interface definition for such an exit monitoring station is again minimized and facilitated by the need for a minimum of detail specification. The M/ES-3 can be placed at whatever point in the exit conveyor seems most appropriate, and performs its function independently of the actual rate of production of the submodule.

If the desired rate of 1440 pieces/minute cannot be achieved in a single in-line system, the submodule interface will divide the flow into two streams. In this case, a dual M/ES-3 approach will be used, similar in concept to that shown for M/ES-1.

The configuration of the various Electronic Modules will be determined largely by the particulars of the sensing devices associated with each station. They may contain sample and hold amplifiers, sense and reset circuitry, pre-amplifiers, and other forms of signal conditioning electronics, depending on the detailed requirements.

In conclusion, it has become increasingly clear that in many respects the problem of high-speed on-line manufacturing inspection of small caliber ammunition demands a quantum jump forward in the measurement field. To develop the necessary inspection techniques within the accelerated SCAMP schedule, requires the imaginative application of all of the scientific disciplines, including modern computer automation technology.

Based on the SCAMP system constraints and requirements for the Waterbury-Farrel Case Submodule, an Automatic Inspection System definition has been accomplished, and a detailed system specification has been prepared. Design and development work is now underway on both the inspection techniques and mechanical portion of the system. It is hoped that this effort will be the vehicle for accelerating significant progress in the new science of high speed testing techniques.

ALBERT CHALFIN
FDDE LAB N7000
Frankford Arsenal
Philadelphia, Pennsylvania 19137

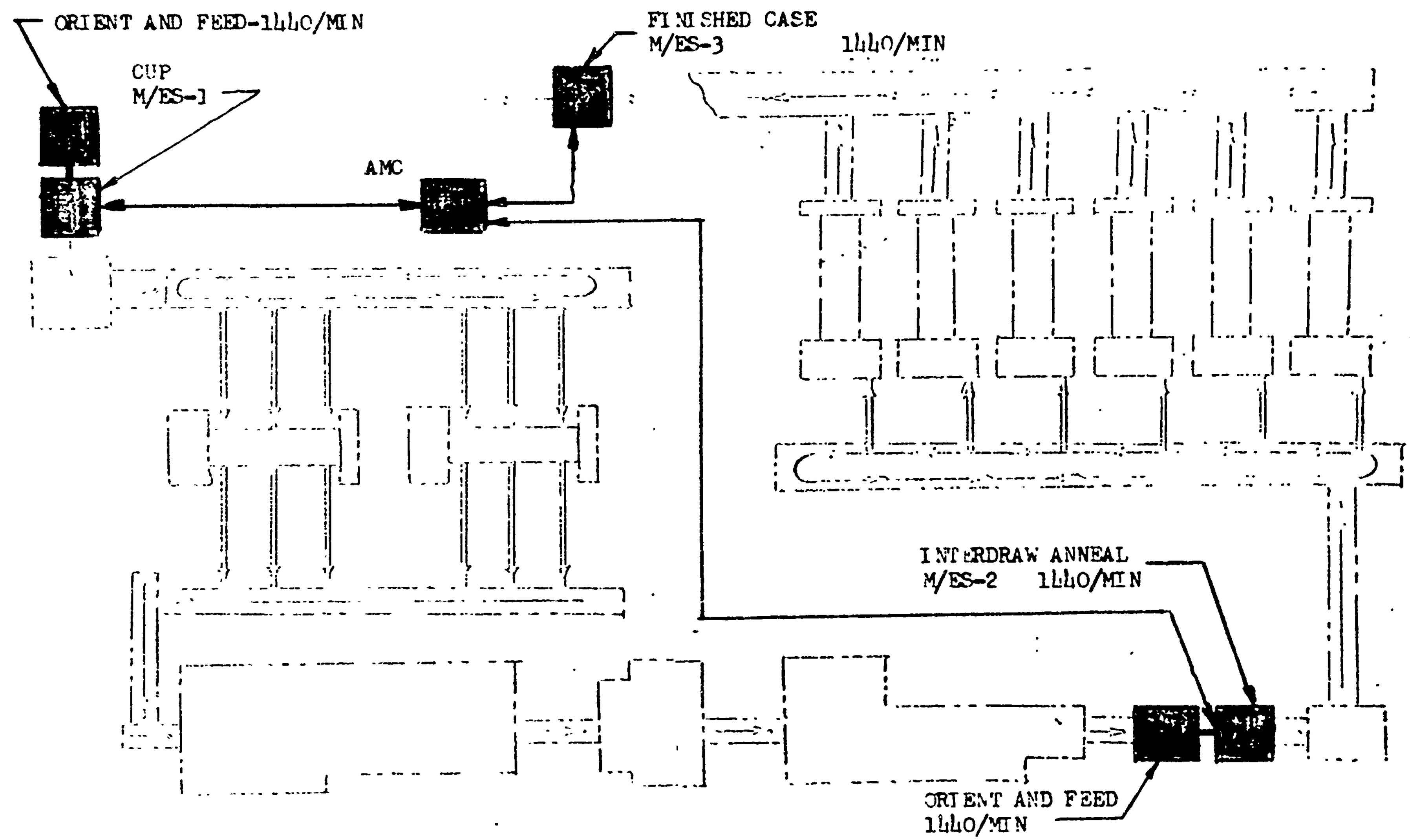
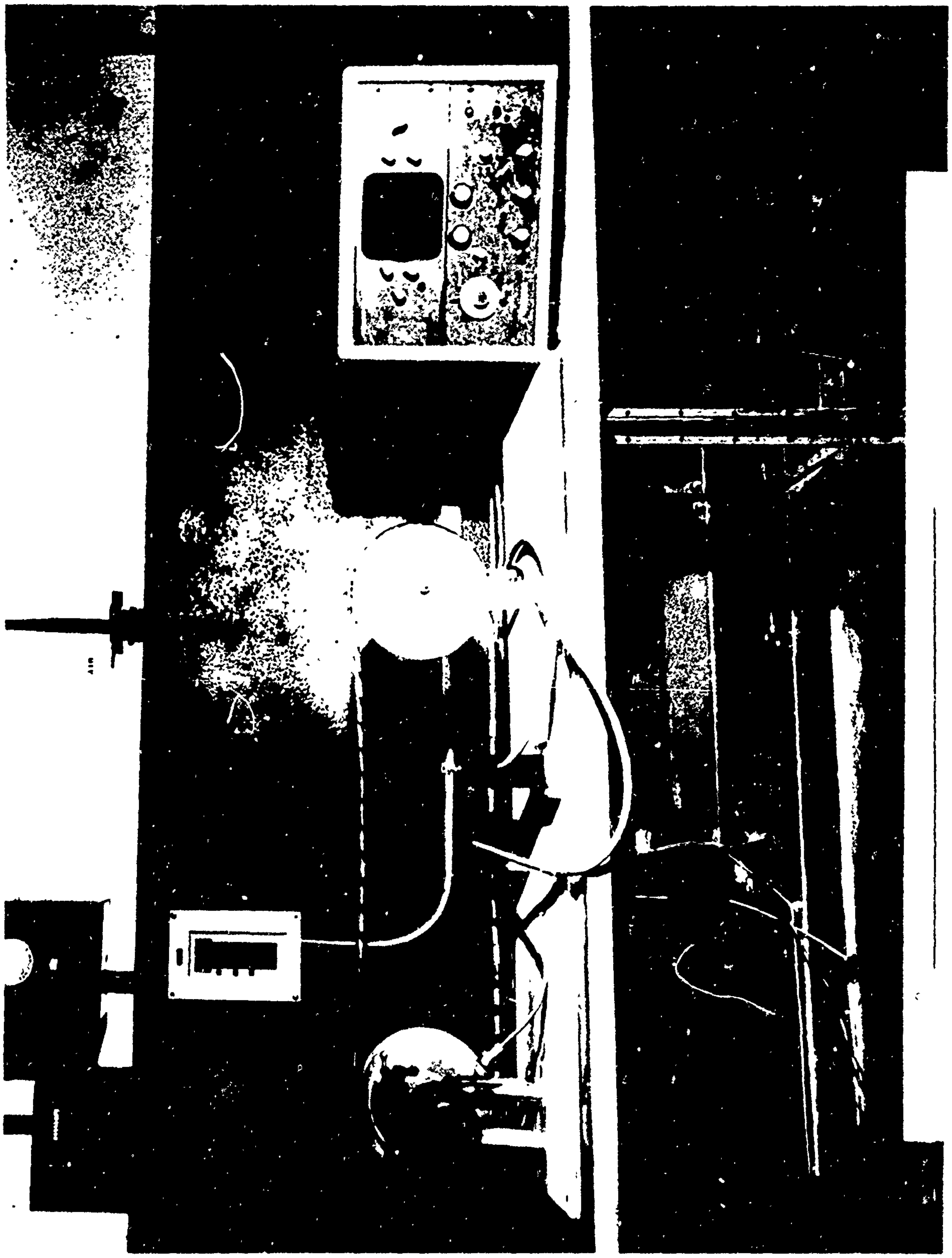
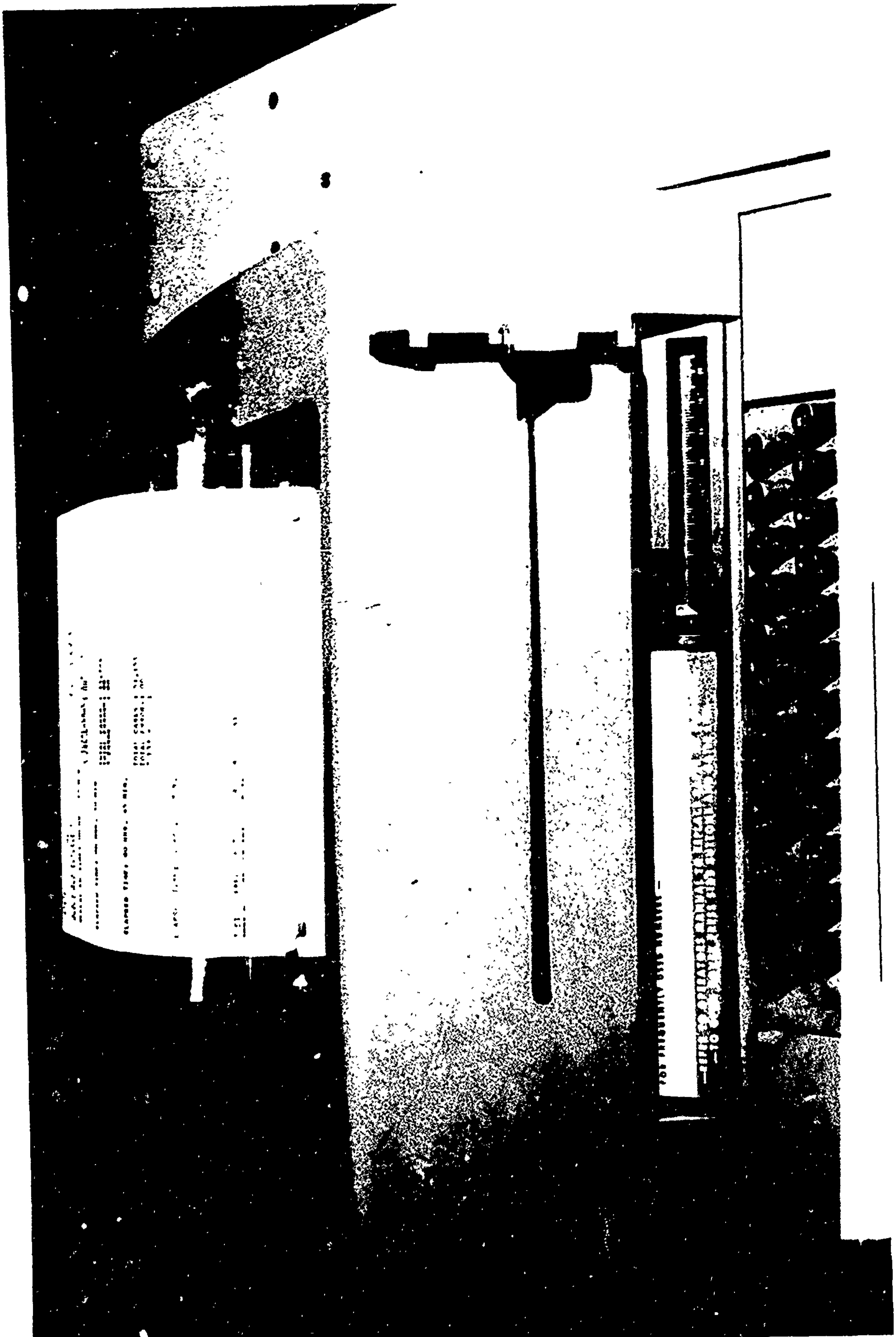
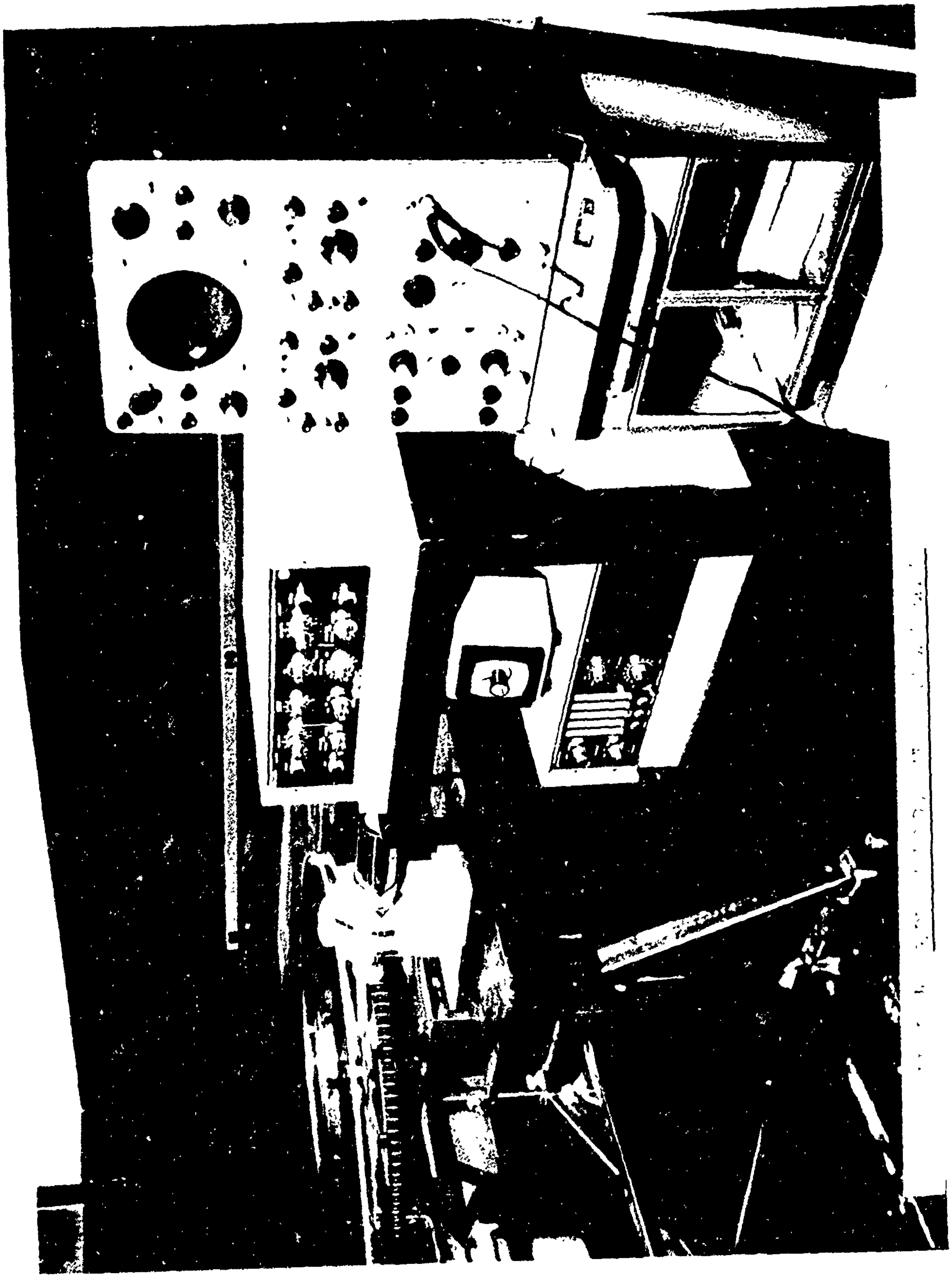


FIGURE 1 WATERBURY-FARREL CARTRIDGE CASE SUBMODULE, INSPECTION SYSTEM







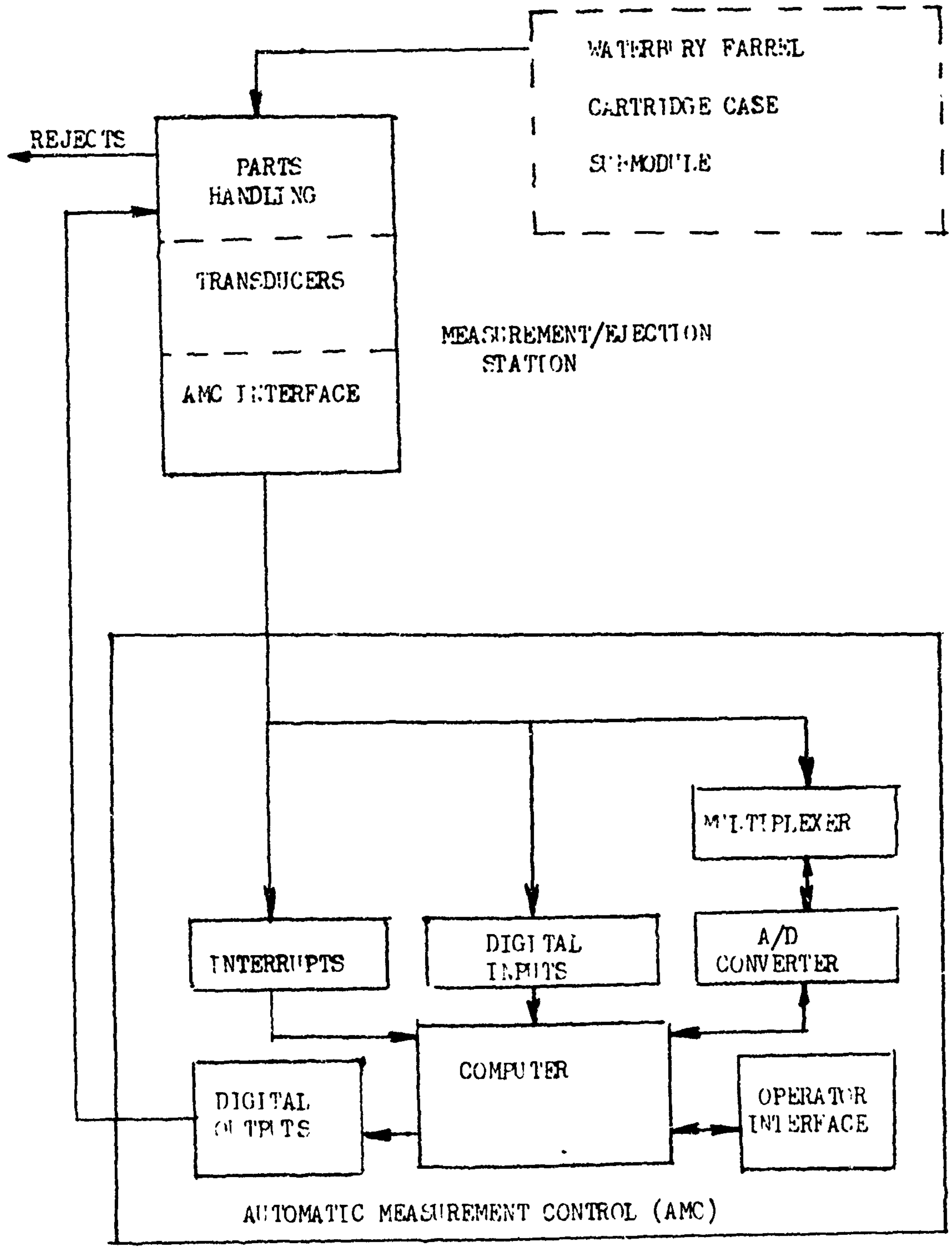


FIGURE 5 AUTOMATIC MEASUREMENT CONTROL, FUNCTIONAL IMPLEMENTATION AND OPERATION INTERFACE

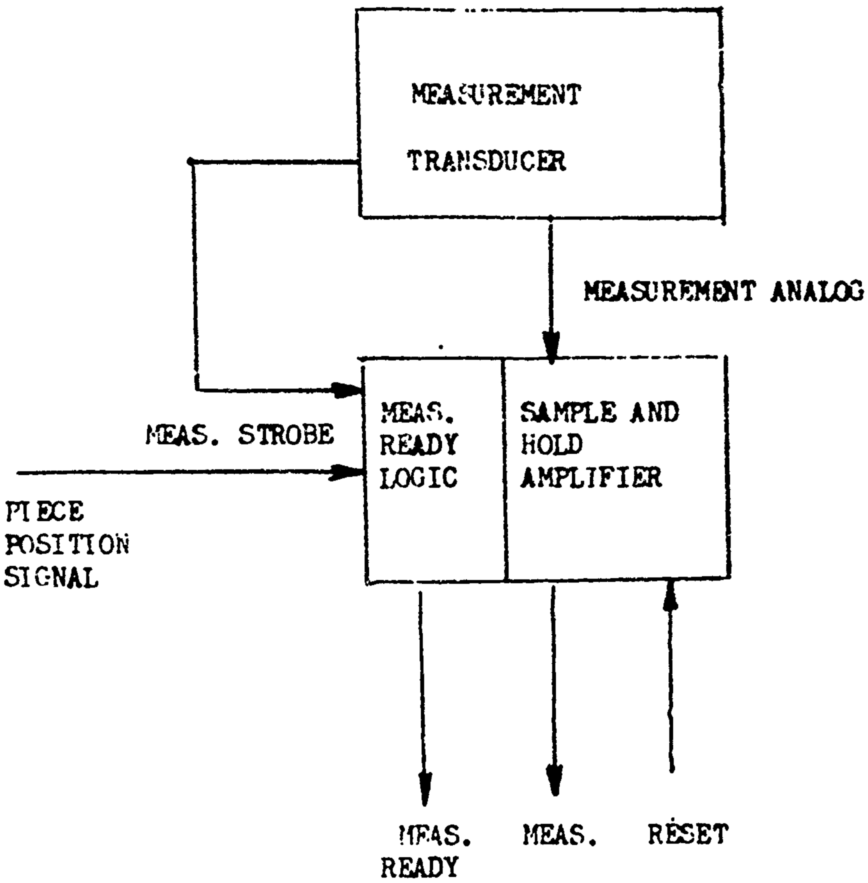


FIGURE 6 INSPECTION-AMC INTERFACE (TYPICAL)

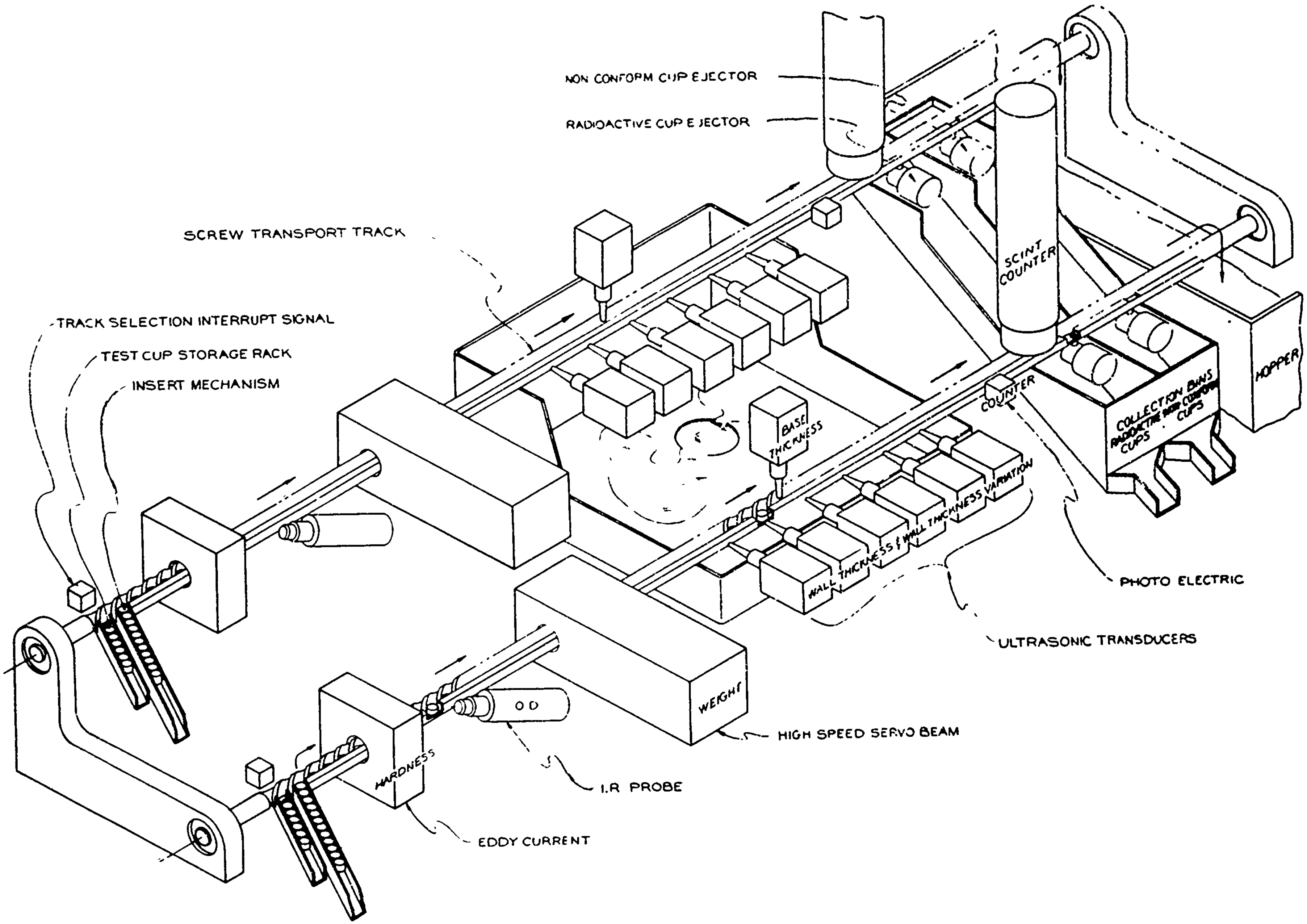


FIGURE 7 MEASUREMENT/EJECTION STATION NO.1

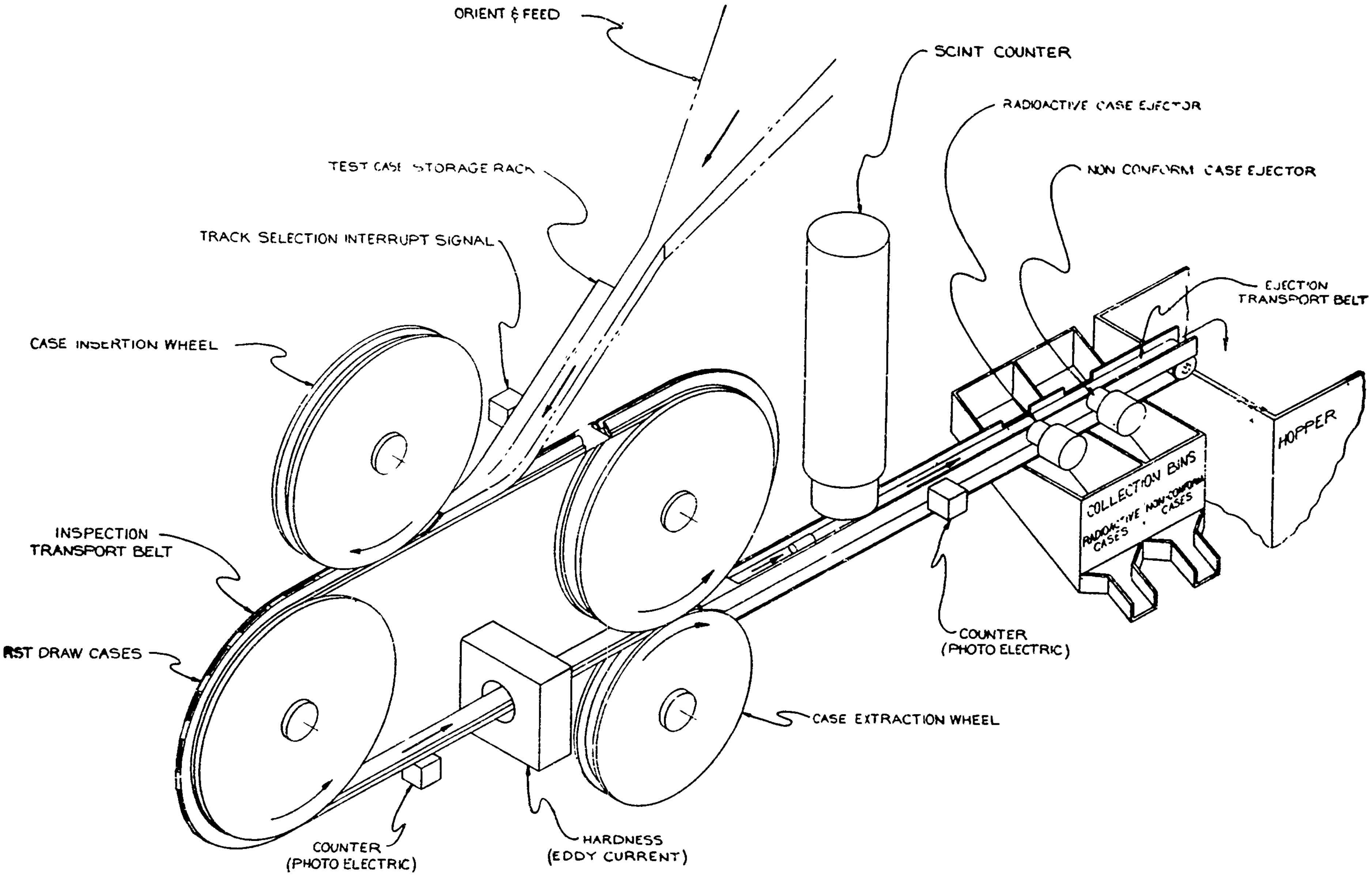


FIGURE 8 MEASUREMENT/EJECTION STATION NO. 2

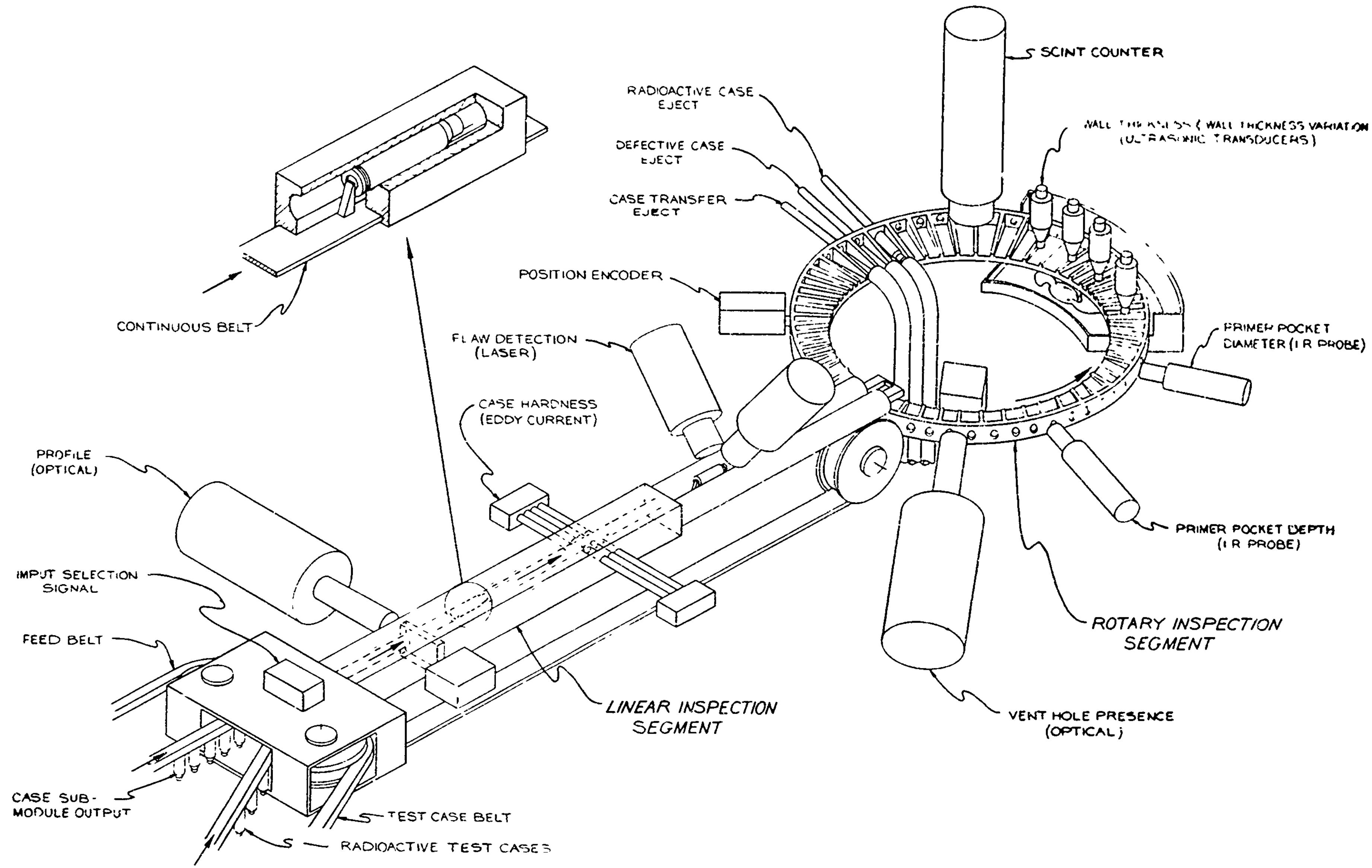


FIGURE 9 MEASUREMENT/EJECTION STATION NO. 3

PAPER NO. 9

Investigation of Organic Composite Characteristics Through Destructive and Nondestructive Test Techniques

Eleanor Th. Vadala

Naval Air Development Center
Aero Materials Department
Warminster, Pennsylvania 18974

ABSTRACT

The Naval Air Development Center has been studying the effect of process variables on the quality of organic matrix composites to establish whether differences can be detected nondestructively. A second objective was to establish a correlation between nondestructive evaluation and destructive tests relative to the quality of the composite. The study involved the preparation of individual 12 ply glass and graphite composites, processing in the autoclave at a high and low level of pressure and heat rise, evaluation with nondestructive test techniques and destructive tests.

Several of the nondestructive techniques indicated a difference in the response of the panels cured at a high and low level of pressure. Panels cured at different rate of heat rise had little effect on the response of these instruments.

The panels cured at high pressure (150 PSI) were of better quality than those cured at low pressure (vacuum); higher interlaminar shear and flexural strength, higher specific gravity and greater density were noted.

A correlation of nondestructive and destructive test results showed that the liquid crystals, Harmonic Bondtester and the Fokker Bondtester were sensitive to the quality and physical characteristics of the organic matrix composites.

PAPER NO. 9

ELEANOR TH. VADALA

INTRODUCTION

Quality control procedures characteristically specify the allowable type and quantity of defects and flaws in composites based on such "practical" considerations as cost, production schedules, and precedent. Excessively conservative standards are responsible for the rejection of much usable material and excessively loose standards result in acceptance of unsatisfactory material. This situation is the consequence of almost complete lack of basic information on the significance of defects in terms of service performance. Increased use of organic composites in aircraft, to reduce weight and to increase operational capability, will demand the availability of reliable nondestructive test methods to establish quality control parameters. The development and implementation of these control requirements will aid in ensuring quality items and ultimately, reduced cost.

The primary objective of this program was to study the effect of process variables on the quality of organic matrix composites to establish whether differences can be detected nondestructively. A second objective was to establish a correlation between nondestructive evaluation and destructive tests relative to the quality of the panel. The study involved (a) the preparation of individual 12 ply glass and graphite laminates, (b) processing in the AMD (Aero Materials Department) autoclave at a high and low level of pressure and rate of heat rise, (c) evaluation with nondestructive test techniques and destructive tests.

EXPERIMENTAL DATA

ORGANIC MATRIX MATERIALS

Individual laminates were made of glass and graphite three inch prepreg tapes.

The epoxy-glass prepreg tape is manufactured by the 3M Company and identified as "Scotchply"* Reinforced Plastic, Type 1002, reference (a). The physical properties of the glass prepreg are presented in Table I.

The graphite tape is manufactured by the British Fothergill and Harvey Ltd., and is identified as "Carboform HT"**, references (b) and (c). This B staged prepreg is a

* 3M Registered Trademark

** Fothergill and Harvey Registered Trademark

TABLE I

PHYSICAL PROPERTIES OF PREPREG TAPES

Property	Identification	
	Glass Type 1002	Graphite-Carboform HT
Resin System	Epoxy-Glass	ERLA 4617/DDM
Resin Content, % (By Weight)	36	35-40
Thickness, in/ply (cured)	.010	.008
Specific Gravity	1.8	1.95

two component system consisting of a high strength carbon fiber impregnated with ERLA 4617 resin matrix (Union Carbide cycloalaphatic epoxy resin) and methylene dianiline (British designation DDM). The prepreg unidirectional tape contains 50%, by volume, of carboform fibers. The physical properties of the graphite are also specified in Table I.

FABRICATION OF COMPOSITE SPECIMENS

The fabrication of the individual 12 ply glass and graphite composites involves three operations:

(1) Ply Orientation and Stacking

(2) Completion of Layup Assembly Pattern

(3) Autoclave Cure Cycle

The plies were oriented and stacked on a 24 inch square by 1/4 inch thick masonite panel prepared with two grooves, 1/4 inch wide by 1/8 inch deep, reference (d). The grooves, at right angles to one another, passed through the center and divided the masonite panel into four 12 inch squares.

A sheet of "Armalon"***, glass fabric impregnated with DuPont TFE (Tetrafluoroethylene, commonly called Teflon), reference (e), was taped to the masonite surface and served as a parting agent. An 18 inch square, with degree markings (42° and 138°) on the outside, was inked on the Armalon. These markings guided the placement of precut three inch wide prepreg tapes during stacking.

The ply stacking arrangement was identical for both the glass and graphite composites. The tape orientation and stacking sequence reflected the NAVAIRDEVCEN interest in laboratory verification of an in-house theoretical computer program for predicting laminate properties from unidirectional material properties and the analysis for the design of an all graphite wing component for the BQM-34E "Firebee" unmanned supersonic aerial target, reference (f). The stacking sequence was as follows:

42°, 0°, 138°, 138°, 0°, 42°, 42°, 0°, 138°, 138°, 0°, 42°

Cardboard patterns were made for cutting the prepreg tape to the proper length and appropriate angle (42° or 138°) to fit into the 18 inch square, Figure (1). As each

*** Registered DuPont Trademark

ply was positioned, a Teflon coated paddle was stroked over the surface to ensure intimate contact. Two cuts, at right angles to one another and passing through the center divided the 18 inch square into four nine inch squares, Figure (1). The graphite was cut after each layer of prepreg tape was positioned. On the glass laminate, a cut was made every two or three layers. No difficulty was encountered in using this procedure although care was needed not to separate the prepreg into the individual fibers at the corners.

The individual nine inch square composites were carefully wrapped in cellophane film and stored in a freezer until ready for curing.

The completion of the layup pattern and curing in the autoclave was done singly.

A stacked prepreg assembly was removed from the freezer and allowed to warm to room temperature. The complete layup sequence for curing in the autoclave is presented below:

(1) One layer of a non-porous Armalon, Teflon coated release sheet, is placed on a supporting caul aluminum plate.

(2) One layer of Miltex, Style 3921 (5 mil), used as a peel ply, is placed over the release sheet.

(3) The 12 ply stacked prepreg assembly (42°, 0°, 138°, 138°, 0°, 42°, 42°, 0°, 138°, 138°, 0°, 42°) is placed in the center of the Miltex.

(4) A boundary support of 0.064 inch cork is placed around the prepreg assembly.

(5) One layer of Miltex, Style 3921 (5 mil) is placed over the graphite composite. This Miltex peel ply was omitted in the glass composite layup.

(6) One layer of Emfab TX-1040, a porous separator fabric is placed over the layup.

(7) One ply of Style 120 glass fabric is placed over the separator sheet.

(8) The entire layup is covered with Style 181 glass fabric. Eleven plies of the fabric were used for the glass layup and six plies were used for the graphite layup.

(9) The entire layup is covered with one layer of the non-porous Armalon release sheet.

(10) A supporting caul plate is placed over the layup.

(11) The entire layup is covered with one layer of Style 181 glass fabric.

(12) The layup is then placed in a vacuum bag and cured.

Due to a higher bleedout of resin, the glass prepreg layup, required the additional layers of 181 glass fabric to provide adequate absorption.

The organic matrix layups were individually placed into the cold autoclave and cured at either a low or high level rate of heating and pressure. The details of the specific curing techniques are presented in Table II.

To monitor thermal conditions, the autoclave is equipped with thermocouples and a recorder. One of the thermocouples measured the chamber temperature and another was affixed to the composite being cured.

IDENTIFICATION OF ORGANIC MATRIX COMPOSITES

The eight laminates (four each of glass and graphite), Figures (2) and (3), were identified by code number and the label was placed on the edge of the 0° side.

The glass composites were identified EHG (Elevated Heat, Glass). The graphite composites were identified EHC (Elevated Heat, Carboform). Subsequent identification denoted the level of the pressure and rate of heating used: V - vacuum pressure (approximately 15 PSI or atmospheric pressure); P - a pressure of 150 PSI; (-5) - heat rise of 5°F/min.; (-10) - a heat rise of 10°F/min. (Table III).

NONDESTRUCTIVE EVALUATION

A plastic stencil, as represented by Figure (4), was made and used to mark the surface of the composites. The edge of one side of the stencil was marked, "TOP". This side was placed on the identification label of the composite. The stencil pattern was inscribed on the composite: pen and pencil were used on the glass composites; white chalk was used on the graphite composites. Measurements were made at approximately one inch intervals on each side within each square. The numbers reported in the Tables

TABLE II

CURING TECHNIQUES FOR THE ORGANIC MATRIX COMPOSITE

Organic Matrix Material	Glass-Type 1002	Graphite-Carboform Type HT with ERLA 4617/DDM
Resin System	Epoxy	Cycloalophatic resin with methylene dianiline curing agent
Prepreg	Unidirectional, 0°	Unidirectional, 0°
Number of Plies	12	12
Layup	One Technique	One Technique
Curing Technique	Autoclave	Autoclave
Entering Temperature	Ambient	Ambient
Cure Temperature,°F	325	330
Heat Rate,°F/Min		
Low Level	5	5
High Level	10	10
Cure Time	35 Min/325°F	1 hr/330°F
Pressure, PSI		
Low Level	Vacuum	Vacuum
High Level	150 150	150
Removal Temperature (Cool under Pressure)	150°F	150°F
Post Cure	35 Min at 325°F 6 hrs at 350°F	6 hrs at 285°F 2 hrs at 320°F
Coupon Cutting Technique	Water cooled diamond wheel	Water cooled diamond wheel

TABLE III

IDENTIFICATION OF THE ORGANIC MATRIX COMPOSITES

Organic Matrix Material	Pressure PSI	Heat Rise °F/Min
Glass System-Type 1002 (Epoxy-Glass)		
EHGV-5	Vacuum	5
EHGV-10	Vacuum	10
EHGP-5	150	5
EHGP-10	150	10
Graphite System-Courtaulds Carbo-form Type HT with ERLA 4617/DDM		
EHCV-5	Vacuum	5
EHCV-10	Vacuum	10
EHCP-5	150	5
EHCP-10	150	10

represent an average of the actual measurements made; total measurements exceed 100 on each panel with each technique.

Thickness measurements were made with a spring loaded indicator. The values are reported in Table IV.

Three nondestructive test techniques were used to evaluate the organic matrix composites: (1) Thermal Methods; Cholesteric Liquid Crystals and the Thermal Inspection System; (2) Sonic Techniques: The Sonic Test System and the Harmonic Bondtester (3) Ultrasonic Method: The Fokker Bondtester.

Thermal Techniques

The basic principle of thermal nondestructive testing is the sequential heating and monitoring of the surface temperature of the subject. The subject is first heated. As the temperature of the subject increases or decreases, the surface temperature is observed. The heat flow within the subject will be affected by defects such as debonds and voids. The difference in heat flow will be detected as a change in the surface temperature. When an advanced composite is heated, heat transfer and dissipation occur more readily if there are no defects.

(a) Cholesteric Liquid Crystals

The liquid crystals, otherwise known as mesomorphic liquids or mesophases, have two melting points. The mesophase is observed when the material is heated to a temperature above which the crystal lattice is stable, reference (g). The crystals will collapse at this first melting point and give a turbid viscous melt. At a higher temperature, this mesophase will flow and become clear giving the isotropic liquid. The first melting point represents the temperature at which the solid and mesomorphic phases are in equilibrium and the second melting point is the temperature at which the mesophase and isotropic liquid phase are in equilibrium. Within these temperature limits the mesomorphic phase is stable and has a remarkable ability to register minute changes in temperature by changing color. If a part is free of defects, colors are uniform and the surface heats or cools consistently, changing from one color to another. If an unbond area is present, it will be evident because of the slower transmission of heat through the debonded area. The colors in this area will lag in transition, thus presenting a clear picture of the void.

TABLE IV

AVERAGE THICKNESS MEASUREMENTS OF GLASS (EHG SERIES) AND GRAPHITE (EHC SERIES) COMPOSITES

		Area	1				2				3				4				
Identification	Center	Side	a	b	c	d	a	b	c	d	a	b	c	d	a	b	c	d	Allover Average Thickness, Ins.
EHGV-5	.098		.100	.100	.101	.099	.099	.099	.100	.100	.097	.100	.099	.098	.094	.094	.096	.091	[illegible]
EHGV-10	.097		.097	.097	.098	.098	.098	.097	.097	.098	.098	098	.097	.099	.093	.095	.095	.095	[illegible]
EHGP-5	.087		.085	.083	.085	.084	.084	.085	.086	.084	.085	.085	086	.086	.084	.082	.083	.077	.084
EHGP-10	.085		.085	.086	.085	.086	.085	.086	.086	.085	.085	.086	.086	.087	.085	.083	.085	.084	.085
EHCV-5	.102		.101	.102	.102	.102	.100	.101	.101	.101	.101	.101	.102	.102	.097	.098	.097	.098	100
EHCV-10	.105		.102	.101	.103	.103	.103	.103	.103	.10[illegible]	.102	.100	.103	.101	.100	.085	.093	.093	.100
EHCP-5	.090		.090	.092	.092	.092	.092	.094	.092	.0[illegible]3	.093	.094	.095	.095	.085	.083	.086	.086	.091
EHCP-10	.091		.091	.090	.093	.093	.092	.091	[illegible]	.093	.093	.092	.094	.092	.086	.086	.083	.089	091

AMD has been studying the use of liquid crystals as an NDT medium, references (g) and (h). A self-adhering plastic film was used as a carrier for the liquid crystals. It was reuseable, retained the temperature color sensitivity for NDT and successfully detected voids in metal to metal bonded joints and in sandwich honeycomb panels. Because this method is based on thermal flow, temperature differences can be observed during heating as well as cooling.

The use of liquid crystals in this study is directed toward the application to the organic matrix composites.

The black pressure sensitive polyester film was placed on the composites and served as the carrier for the cholestric liquid crystal blend (90% cholesteryl pelargonate and 10% cholesteryl myristate in toluene). Although colorless as an isotropic liquid, the cholesteric blend goes through a series of bright iridescent colors as it passes through its liquid phase (70° to 89°C). The color transition of the liquid crystals was observed to be similar on all of the panels. The area of the mesophase gradually increased with continued application of heat and decreased when cooled. It was observed that the color changes were uniform and the surface heated and cooled consistently, thus, it can be assumed that there are no defects within the composites to cause differences in the heat flow. It was noted, however, that the various panels showed differences in the time of the appearance and duration of the mesophase. Experiments were conducted to determine the relationship of the time differences to the quality of the panel.

In the first experiment, the test panels were heated on a hot plate, removed and cooled with a fan. The time for the appearance of the mesophase of the first melt was recorded. The laminates were heated a total of 90 or 120 seconds, Tables (V) and (VI). The approximate area of the mesomorphic phase nature of the color change and the time for recrystallization was noted.

In a second experiment with the liquid crystals the hot plate was replaced with a heat gun (Thermogun). The heat gun was placed 12 inches behind the laminate and the heat applied until a circle of approximately 5 1/2 inches in diameter of the mesophase was obtained. The time, Tables VII and VIII, for the beginning of the mesophase melt, the total heat time to obtain the circle of the mesophase and the time for recrystallization after removal of the heat, was recorded.

TABLE V

NONDESTRUCTIVE EVALUATION OF GLASS (SCOTCHPLY TYPE 1002) COMPOSITES WITH LIQUID CRYSTALS AND A HOT PLATE THERMAL SOURCE

	Time to Mesomorphic Phase (First Melt) Secs.	Total Heat Time Secs.	Approximate Area of Mesomorphic Phase Ins.	Time for L.C. to Recrystallize Secs.	Comments
EHGV-5-a	28	90	5 X 4	40	Uniform Color Transition
-b	29	150	6½ X 6 3/8	63	Uniform Color Transition
-c	29	150	6½ X 6 3/8	55	Uniform Color Transition
EHGV-10-a	27	150	6½ X 6½	47	Uniform Color Transition
-b	27	150	6½ X 6½	65	
-c	27	150	6 3/4 X 6 3/4	57	Color Transition but Lags as though Air Pockets exist
EHGP-5-a	17	150	2 3/4 X 3½	65	Uniform Color Transition
-b	18	150	4½ X 3½	47	Uniform Color Transition
-c	17	150	3½ X 4½	41	Uniform Color Transition
EHGP-10-a	18	150	3½ X 5½	-*	Uniform Color Transition
-b	20	150	4½ X 6	57	Uniform Color Transition
-c	18	150	4 X 6	47	Uniform Color Transition

*Not Recorded

TABLE VI

NONDESTRUCTIVE EVALUATION OF GRAPHITE (CARBOFORM TYPE HT) COMPOSITES WITH LIQUID CRYSTALS AND A HOT PLATE THERMAL SOURCE

	Time to Mesomorphic Phase (First Melt) Secs.	Total Heat Time Secs.	Approximate Area of Mesomorphic Phase Ins.	Time for L.C. to Recrystallize Secs.	Comments
EHCV-5a	15	90	7½ X 7½	47	Uniform Color Transition
-5b	16	120	8 X 7	54	Uniform Color Transition
-5c	22	120	7 X 6½	55	Uniform Color Transition
-5d	13	90	7½ X 6½	45	Uniform Color Transition
-5e	13	90	7½ X 6½	43	Uniform Color Transition
EHCV-10a*	3*	90*	9 X 9*	206*	Uniform Color Transition
-10b	13	120	7 X 6½	48	Uniform Color Transition
-10c	22	120	7 X 6½	35	Uniform Color Transition
-10d	27	120	7 X 7	52	Uniform Color Transition
-10e	16	90	7 X 6 3/4		Uniform Color Transition
EHCP-5a	12	90	6 X 6	43	Uniform Color Transition
-5b	9	90	6 X 7	43	Uniform Color Transition
-5c	12	90	5 3/4 X 6	41	Uniform Color Transition
-5d	12	90	6 3/4 X 6	43	Uniform Color Transition
EHCP-10a	31	90	6 X 2½ Irreg. Pattern	21	Indications of Unequal Heating
-10b	36	120	2 X 6½ Irreg. Pattern	-**	Indications of Unequal Heating
-10c	32	90	7 X 2 Irreg. Pattern	26	Indications of Unequal Heating
-10d	45	90	7 X 2 Irreg. Pattern	27	Indications of Unequal Heating

*Commercial Film
**Not Recorded

TABLE VII

NONDESTRUCTIVE EVALUATION OF GLASS (SCOTCHPLY TYPE 1002) COMPOSITES WITH LIQUID CRYSTALS AND A HEAT GUN (THERMO-GUN) THERMAL SOURCE

	Time to Mesomorphic Phase (First Melt) Secs.	Time from First Melt to 5½" Circle of Mesophase Secs.	Total Heat Time Secs.	Time for L.C. to Recrystallize Secs.	Comments
EHGV-5-1	68	104	172	106	Uniform Color Transition
-2	72	149	221	105	Uniform Color Transition
-3	60	98	158	98	Uniform Color Transition
-4	71	109	180	109	Uniform Color Transition
EHGV-10-1	68	102	170	105	Uniform Color Transition
-2	69	127	196	103	Uniform Color Transition
-3	61	76	137	100	Uniform Color Transition
EHGP-5-1	59	91	150	90	Uniform Color Transition
-2	55	95	150	87	Uniform Color Transition
-3	56	78	134	87	Uniform Color Transition
EHGP-10-1	56	94	150	87	Uniform Color Transition
-2	53	75	128	88	Uniform Color Transition
-3	54	76	130	85	Uniform Color Transition

TABLE VIII

NONDESTRUCTIVE EVALUATION OF GRAPHITE (CARBOFORM TYPE HT) COMPOSITES WITH LIQUID CRYSTALS AND A HEAT GUN (THERMO-GUN) THERMAL SOURCE

	Time to Mesomorphic Phase (First Melt) Secs.	Time from First Melt to 5½" Circle of Mesophase Secs.	Total Heat Time Secs.	Time for L.C. to Recrystallize Secs.	Comments
EHCV-5-1	60	90	150	87	Uniform Color Transition
-2	51	76	127	80	Uniform Color Transition
-3	55	63	118	83	Uniform Color Transition
EHCV-10-1	57	90	147	87	Uniform Color Transition
-3	60	99	159	88	Uniform Color Transition
EHCP-5-1	50	90	140	78	Uniform Color Transition
-2	44	66	110	72	Uniform Color Transition
-3	42	97	139	71	Uniform Color Transition
EHCP-10-1	51	74	125	79	Uniform Color Transition
-2	46	60	104	66	Uniform Color Transition
-3	50	66	116	77	Uniform Color Transition

(b) Thermal Inspection System

The Thermal Inspection System, developed by Automation Industries, reference (h), consists of a hand-held scanning head, operator's control console and interconnecting cable. Figure (5). The necessary hardware and electronics to sequentially heat and scan the surface temperature of the test specimens are included in the head. Signal processing, electronics, display oscilloscope recorder and operator's controls are enclosed in the control console.

The scanning head contains the necessary hardware to perform the heating, temperature detecting and scanning functions. A pistol grip trigger switch controls the start and end of the test.

Scanning in the forward direction is accomplished by driving the rear wheels at a preset forward speed determined by a control console setting. Scanning perpendicular to the forward direction is provided by a rotating mirror within the scanner. Infrared radiant energy from the surface is collected by the scanner optical system and focused on an infrared detector. The facsimile recorder is synchronized to the forward speed and rotating scanning mirror of the scanning head. This arrangement results in a 1-1 scale thermal mapping of the test surface temperature along a three inch wide test path.

Typical thermograms obtained for the glass and carboform composites are presented in Figures (6) and (7).

Sonic Systems

(a) Sonic Test System

The Sonic Test System, Figure (8), is a portable unit that consists of interchangeable Eddysonic and Sonic Resonator plug in modules. The Eddysonic module is applicable only to composites containing metal and the Sonic Resonator is particularly suitable for nonmetallic structures. The Sonic Test System contains a tunable audio oscillator, amplifier, transducer (probe), tuned amplifier and detector.

The Sonic Resonator operates by acoustic interferometry, reference (j). A small, resonant piezoelectric probe generates an audio (or near audio) frequency standing wave throughout a localized sectional

thickness of the test material. The phase and amplitude of the standing wave are sensed by the same probe and indicated as a lumped value of a meter. Structural defects alter these standing wave characteristics and are detected by changes in the meter reading. A light film of liquid must be applied to the test surface to insure efficient energy coupling.

No satisfactory sensitivity or test frequency could be found that could detect differences in the panels. Various probes on hand (19D6SN 199, 21 D6 SN 107 and 107 SN 181) and a wide range (20-80) were tried. No systematic measurements were made.

(b) Harmonic Bondtester

The Harmonic Bondtester, Figure (9), operates on a resonant sonic principle and excites vibrations into the material to be tested. It is the acoustical response of the material to these vibrations which is used to distinguish a sound structure from a defective one.

The basic unit is a black box which provides the electronics to drive the second unit, the search probe, reference (k). The search probe consists of a coil wound within a pot core that generates a magnetic field which will create eddy currents when placed on a material that is conductive. In the center of the probe is a "listening" system consisting of a special piezoelectric crystal element. This picks up the signal from the subject under evaluation.

For structures containing nonconductive material such as glass, the probe itself mechanically vibrates the panel by direct contact.

Because the acoustic energy is introduced into the laminate through electromagnetic coupling, no liquid couplant is required.

The evaluation of the panels is presented in Table IX.

Ultrasonic Test Equipment

(a) Fokker Bondtester

The Fokker Bondtester, Figure (10), is an ultrasonic resonance test equipment that operates on the principle that a piezoelectric crystal, vibrating at a natural frequency is sensitive to the load coupled to it,

TABLE IX

NONDESTRUCTIVE EVALUATION OF GLASS (EHG SERIES) AND GRAPHITE (EHC SERIES) COMPOSITES WITH THE HARMONIC BONDTESTER

		Area	1				2				3				4				
Identification	Center	Side	a	b	c	d	a	b	c	d	a	b	c	d	a	b	c	d	Allover Average
EHGV-5	7		7	7	7	8	7	6	7	7	6	7	7	7	7	5	7	6	7
EHGV-10	10		10	12	11	13	19	21	17	14	14	20	25	13	17	21	28	17	17
EHGP-5	46		40	32	42	43	39	26	41	29	33	17	33	22	24	10	29	9	30
EHGP-10	43		37	46	45	31	33	26	40	29	23	24	34	28	18	19	30	12	30
EHCV-5	20		21	23	24	23	23	20	22	22	25	19	24	20	21	21	22	26	22
EHCV-10	1		28	23	28	23	28	37	32	25	19	20	27	25	29	33	25	36	25
EHCP-5	15		35	38	28	30	39	30	27	33	13	11	22	19	20	9	24	17	24
EHCP-10	40		38	41	39	38	35	32	39	34	32	31	38	35	36	34	36	37	36

Harmonic Bondtester Settings - Frequency: 110 Output: Hi Sensitivity: 850

reference (k). A measurement of the effect of the load on the vibrational behavior of the crystal is used to describe the properties of the test specimen.

When the crystal or transducer is loaded by placing on a bonded structure, the amplitude and frequency change by an amount that depends on the physical properties of the structure. The probe of the tester (transducer) is driven by a sweep frequency of constant amplitude. The transducer used is a polarized polycrystalline ceramic, barium titanate, which generates electric charges when mechanically stressed and conversely becomes stressed when electrically excited. As a result, the transducer develops a voltage across its flat face. The voltage developed across the crystal is displayed on an oscilloscope, A Scale, and its amplitude measured by a meter, B Scale. The voltmeter indicates the amount of damping in the transducer vibration and the oscilloscope indicates the shift in resonant frequency.

Results of nondestructive evaluation are presented in Tables X and XI.

Polaroid pictures were taken of the A and B Scales on the Fokker Bondtester with the MP-3 Land camera with P/N Type 55 film and using the existing lights. The physical arrangement is designed below:

Subject to Lens Distance	12 Inches
Aperature	F16
Exposure Time	12 Seconds

Figure (11) is a picture of the A and B Scales before placing the transducer on a panel for evaluation.

Figures (12) through (15) show the effect of loading on the oscilloscope and meter.

DESTRUCTIVE TESTS

The flexural, horizontal shear, density and specific gravity specimens were taken from each 9 inch square panel in accordance with the diagram in Figure (16). These specimens were cut to size using a water cooled diamond wheel.

TABLE X

NONDESTRUCTIVE EVALUATION OF GLASS (TYPE 1002) COMPOSITES WITH THE FOKKER BONDTESTER

		Area	1				2				3				4			
	Center	Side	a	b	c	d	a	b	c	d	a	b	c	d	a	b	c	d
A SCALE																		
EHGV-5	2L		2.0L	1.8L	2.0L	2.0L	2.0L	2.0L	1.7L	2.0L	2.0L	1.9L	1.6L	2.0L	2.6L	2.5L	2.5L	2.8L
EHGV-10	2L		2.0L	1.9L	2.0L	2.0L	1.9L	2.0L	2.0L	2.0L	1.9L	2.0L	1.9L	2.0L	2.3L	2.4L	2.1L	2.1L
EHGP-5	6L		6.3L	6.0L	6.0L	6.0L	5.7L	5.9L	6.2L	6.2L	5.1L	5.7L	5.9L	5.8L	5.8L	5.8L	5.5L	5.8L
EHGP-10	5L		5.0L	5.3L	5.2L	5.2L	5.0L	5.1L	5.4L	5.2L	5.1L	5.0L	5.0L	5.0L	5.0L	4.8L	5.0L	5.2L
B SCALE																		
EHGV-5	60		60	59	57	60	58	57	56	58	57	59	61	60	53	58	58	57
EHGV-10	61		62	62	62	61	61	60	62	61	61	63	62	61	58	60	63	61
EHGP-5	35		32	37	34	36	33	39	32	34	29	36	37	40	30	31	29	32
EHGP-10	46		50	45	45	45	51	50	47	51	49	56	57	54	47	48	52	47

TABLE XI

NONDESTRUCTIVE EVALUATION OF GRAPHITE (CARBOFORM, TYPE HT) COMPOSITES WITH THE FOKKER BONDTESTER

		Area	1				2				3				4			
	Center	Side	a	b	c	d	a	b	c	d	a	b	c	d	a	b	c	d
A SCALE																		
EHCV-5	.9L		1.0L	1.0L	1.2L	1.0L	0.7L	0.9L	0.9L	0.7L	0.9L	1.0L	0.9L	0.8L	0.8L	1.0L	1.0L	0.9L
EHCV-10	1.0L		1.1L	1.6L	1.4L	1.7L	1.0L	0.9L	1.1L	1.0L	0.9L	0.9L	0.9L	0.9L	1.0L	1.0L	1.0L	1.0L
EHCP-5	4.1L		3.5L	3.9L	3.5L	3.8L	3.1L	3.0L	3.0L	3.2L	3.7L	3.3L	3.3L	3.2L	4.0L	4.0L	3.8L	4.0L
EHCP-10	5.2L		4.7L	4.9L	4.8L	4.9L	4.6L	4.8L	4.8L	4.5L	4.8L	4.9L	4.5L	4.5L	4.8L	4.9L	5.1L	4.8L
B SCALE																		
EHCV-5	68		67	65	67	64	66	60	60	55	62	57	61	67	66	58	65	64
EHCV-10	70		70	67	65	66	64	65	55	61	65	65	62	55	67	69	66	65
EHCP-5	48		56	53	54	53	40	44	55	47	39	42	49	50	39	47	48	48
EHCP-10	45		31	30	27	34	33	35	35	51	31	5	38	39	39	36	33	32

The test methods are specified in Table XII. After completing the horizontal shear test, these specimens were used to determine the resin content. The resin content of the glass laminates were determined in accordance with Federal Test Method Standard No. 406, Method 7061; the specimens were kept overnight in a muffle furnace at a temperature of 1050 ± 50°F.

The results of the destructive tests are presented in Table XIII.

MICROSCOPE EXAMINATION

Photomicrographs were taken of the end view of two graphite laminates, EHCV-10 and EHCP-10, using the Reichert bench model microscope and the Hacher Land Model camera. A magnification of 56 was used and several photomicrographs were taken to cover the entire cross section. The photomicrographs were combined into the montage shown in Figure (17).

DISCUSSION

The results of thickness measurements show that the organic matrix composites fabricated under vacuum are 8 to 13 mil thicker than panels made under 150 PSI pressure. This difference in thickness is attributed to the squeeze out of resin under pressure. The glass composites, cured under 150 PSI, have 4.5 to 5% less resin content than those cured under vacuum; graphite laminates lose 3% resin content when cured at 150 PSI.

Within each series, the 150 PSI pressure cured panels have the best mechanical strengths. The rate of heating has no effect on the properties of the glass panels.

The effect of the rate of heating on the physical and mechanical properties of the graphite composites, however, is inconclusive. The EHCV-5 panel yielded higher interlaminar shear and flexural strengths but lower flexural modulus than the EHCV-10 panel. The reverse is true of the EHCP-10 panels. The EHCP-10 panel yielded the higher interlaminar shear and flexural strength than the EHCP-5 panel.

The results of this study give an estimate of the sensitivity that can be expected from the nondestructive techniques.

TABLE XII

LAMINATE TEST METHODS

Flexural Strength and Modulus	Federal Test Method Standard No. 406 Method 1031	Use a 16 to 1 span to thickness ratio for 3 point lcading
Horizontal Shear Strength	NADC-MA-7021 Flexure Test Using a short Specimen	Use a rectangular cross section bar with a 0.6 inch length taken in the 0° direction of the ply layup. A specimen width of 0.5 inch width is used on cross ply laminates
Resin Content	Whittaker Corporation procedure in NADC-MA-7021	Digest for 4 hours at 140°F in fuming nitric acid; use shear coupons
Density	Federal Test Method Standard No. 406 Method 5011	
Thickness Ply	Micrometer thickness measure	

TABLE XIII

RESULTS OF DESTRUCTIVE TESTS

	Horizontal Shear PSI	Ult. Flexure Str. PSI $x10^3$	Flexure Modulus PSI $x10^6$	Specific Gravity	Density lb/in^3	Resin by Weight %
EHGV-5	5803	91.9	2.43	1.825	.06576	28.00
EHGV-10	6238	88.8	2.71	1.850	.06666	27.80
EHGP-5	6154	100.8	2.91	1.9710	.07103	22.95
EHGP-10	6128	100.8	2.93	1.9348	.06972	23.58
EHCV-5	5067	84.6	4.96	1.500	.05409	30.25
EHCV-10	4941	76.6	7.2	1.486	05358	30.17
EHCP-5	7267	92.8	7.6	1.559	.05616	27.56
EHCP-10	8828	131.9	6.2	1.588	.05722	27.28

Tested in the 0° Direction

The Thermal Inspection System and the Harmonic Bondtester require dry contact with the specimen. A wet couplant is used with the Fokker Bondtester and the Sonic Test System. The liquid crystals require a black background and intimate contact since the colors are seen by reflected light.

The range of specimens in this study was limited to organic matrix composites. These were processed at a high and low level of pressure and a high and low level of rate of heating. Effective utilization of any nondestructive instrument is based on calibration of the unit using bonded specimens of known quality. This study is limited to a comparison of four specimens each within two series. Consequently, the separation in the values of the nondestructive test data and the correlation with physical and mechanical test data served as the basis of comparison.

THERMAL TECHNIQUES

In principle the thermal methods are simple. Heat is placed into the test specimens and the temperature response is a result of the conditions within the specimen. Of the two thermal techniques used, the Thermal Inspection System did not show a difference in the response of the panels. The thermograms, Figures (7) and (8), indicated that the panels were free of defects and flaws.

The other thermal technique used the temperature color sensitivity of a cholesteric liquid crystal blend.

The transient temperature differences of the liquid crystals evidenced by the 150 PSI cured panel are generally shorter in time duration and of lower magnitude thus producing smaller areas of the mesophase for a given set time, Tables V and VI.

Examination of the mechanical and physical test data, Table XIII, shows that the pressure cured panels have higher interlaminar shear and flexural strength, higher specific gravity, and density, lower resin content and they are not as thick as the vacuum cured panels.

A correlation of the physical and mechanical test results with the nondestructive evaluation using the liquid crystals indicated that the liquid crystals are sensitive to the quality and thickness of the panels. The temperature difference in the better quality and thinner panels showed higher thermal diffusivity, shorter duration and lower magnitude than the panels of lesser quality and greater thickness.

SONIC TECHNIQUE

The response of the glass composites to the Harmonic Bondtester indicated a difference in the pressure and the vacuum cured panels. The rate of heating, however, did not affect the results of the evaluation with this instrument.

Glass is a nonconductive material and as such cannot produce eddy currents to energize the composite panel. The inherent vibrations of the probe itself, however, will vibrate the glass composite. Thus, it is the response of the subject panel itself, to the vibrating probe, and not the conditions within the panel, that is measured.

A correlation of the nondestructive test evaluation with the physical test data indicated that the thickness of the glass composites and the vibrational behavior are directly related to one another. The readings from the instrument vary as a function of the panel thickness; the thicker the panel, the lower the reading.

Graphite is a conductive material and can produce eddy current to energize the composite panel. The graphite panels, however, did not give a definitive response to the Harmonic Bondtester. The results indicate that the instrstrument was not sensitive to the quality or thickness of the composite. There was little difference in the response of the two graphite panels cured under vacuum, EHCV-5 and EHCV-10, and the one panel cured using 150 PSI and a heat rise of 5° F/min. (EHCP-5). The other 150 PSI cured panel, EHCP-10, showed a somewhat higher response to the injected energy of the Harmonic Bondtester but this could not be correlated to the quality.

Graphite is a conductor but it is a poor electrical conductor. It is hypothesized that the poor response of the graphite panels may be due to its relatively low electrical conductivity.

ULTRASONIC TECHNIQUE

The results of the evaluation of the composite panels with the Fokker Bondtester indicated a difference in the pressure and vacuum cured panels. On the A scale, the greatest shift in the resonant frequency was associated with the pressure cured composites. On the B scale, the lower readings were associated with the pressure cured panels.

The panels cured with different rates of heating did not affect the voltage display on the A scale or the change in amplitude on the B scale.

A correlation of the physical and mechanical properties of the composites with the results of the nondestructive evaluation with the Fokker Bondtester indicate that this instrument is sensitive to the quality and physical characteristics of the panels. The panels cured at high pressure were of better quality than those cured with low pressure; higher interlaminar shear and flexural strength, higher specific gravity and greater density were noted. These composites showed the greatest frequency shift and the lowest amplitude when evaluated with the Fokker.

MICROSCOPIC EXAMINATION

The microscopic examination indicated that the pressure cured (EHCP-10) laminate has better compaction, less microporosity and less resin. The material has a high surface roughness and an increase depth of focus is required to make a detailed study of the observed differences.

SUMMARY OF RESULTS

The nondestructive test instruments detected differences in the panels processed at two levels of pressure. These instruments, however, did not detect the existence of differences in the panels processed at two levels of rate of heat rise.

The panels cured with high pressure (150 PSI) were of better quality than those cured with low pressure (vacuum or atmospheric pressure); higher interlaminar shear and flexural strength, higher specific gravity and greater density were noted. These panels also contained less resin and were not as thick as the vacuum cured panels.

Five nondestructive techniques for detecting quality differences in the glass and graphite laminates have been investigated. These techniques included thermal, sonic and ultrasonic systems.

The thermal systems included liquid crystals and the Thermal Inspection System. The latter system was ineffective in distinguishing differences in the quality of glass and graphite laminates. The liquid crystals indicated a sensitivity to the thermal properties of the pressure cured panels. The better quality panels exhibited a

greater thermal diffusivity as evidenced by a response of shorter duration and lower magnitude.

The sonic technique included the Sonic Test System and the Harmonic Bond Tester. The former technique was ineffective in detecting a difference in the quality of the panels. The Harmonic Bond Tester, however, was effective in detecting a difference in the pressure cured glass panels. The readings from the instrument vary as a function of the panel thickness. The Harmonic Bond Tester did not give a definitive response to the graphite panels.

The Fokker Bond Tester proved to be the best instrument for evaluating the quality of the laminates. Both the damping of the transducer vibration and the shift in resonance showed a sensitivity to the physical characteristics of the panel.

CONCLUSIONS

A qualitative evaluation of glass and graphite composites, processed at a high and low level of pressure, can be made with thermal, sonic or ultrasonic nondestructive techniques.

The nondestructive techniques indicate a sensitivity to:

(1) Thermal conductivity of the composite

(2) Physical and mechanical properties of the laminates such as thickness, density, specific gravity, interlaminar shear and flexural strength.

Higher pressure produced better quality composites.

The physical properties and the mechanical strength of the panels are not affected by the rate of heat rise as much as they are by a change in the applied pressure.

ACKNOWLEDGEMENTS

The effort of other High Polymer Division Personnel associated with this program and their contributions are recognized and acknowledged. Messrs. W. Kelly, C. Freidberg, J. R. Jamsky and H. Snyder in laying up, fabricating of the laminates and for conducting the mechanical testing.

Appreciation is also expressed to Mr. Gwynn K. McConnell of the Metallurgical Division for his suggestions and instructions in the use of nondestructive techniques.

ELEANOR TH. VADALA
Aero Materials Department
Naval Air Development Center
Warminster, Pennsylvania 18974

REFERENCES

(a) 3M Company Technical Data Sheet, Type 1002, "Scotchply" Reinforced Plastic Brand, dated 1 January 1963

(b) Fothergil & Harvey Ltd. Technical Data Sheet, "Carboform Prepregnated High Performance Carbon"

(c) Fothergil & Harvey Ltd. Technical Brochure, "Designing with Carboform Carbon Fibre Reinforced Plastic"

(d) NAVAIRDEVCEN Memo J. Jamsky to L. C. Ritter

(e) DuPont Technical Brochure, "Industrial Fabrics", 1969, Industrial Fabrics Section, Wilmington, Delaware

(f) Report No. NADC-MA-7021, "Property Characterization of High Modulus Fiber Reinforced Composites" dated 21 April 1970

(g) Vadala, E. Th. "Development of a Reusable Strippable Film as a Carrier for Liquid Crystals for Use in NDT", Report No. NADC-MA-6922 dated 22 May 1969

(h) Vadala, E. Th. "Reusable Strippable Film as a Carrier for Liquid Crystals for Use in NDT", NADC-MA-7015 dated 30 March 1970

(i) Technical Report 69-55, "Development of a Thermal Nondestructive Inspection System to Detect Corrosion in Aircraft Structures" Final Report

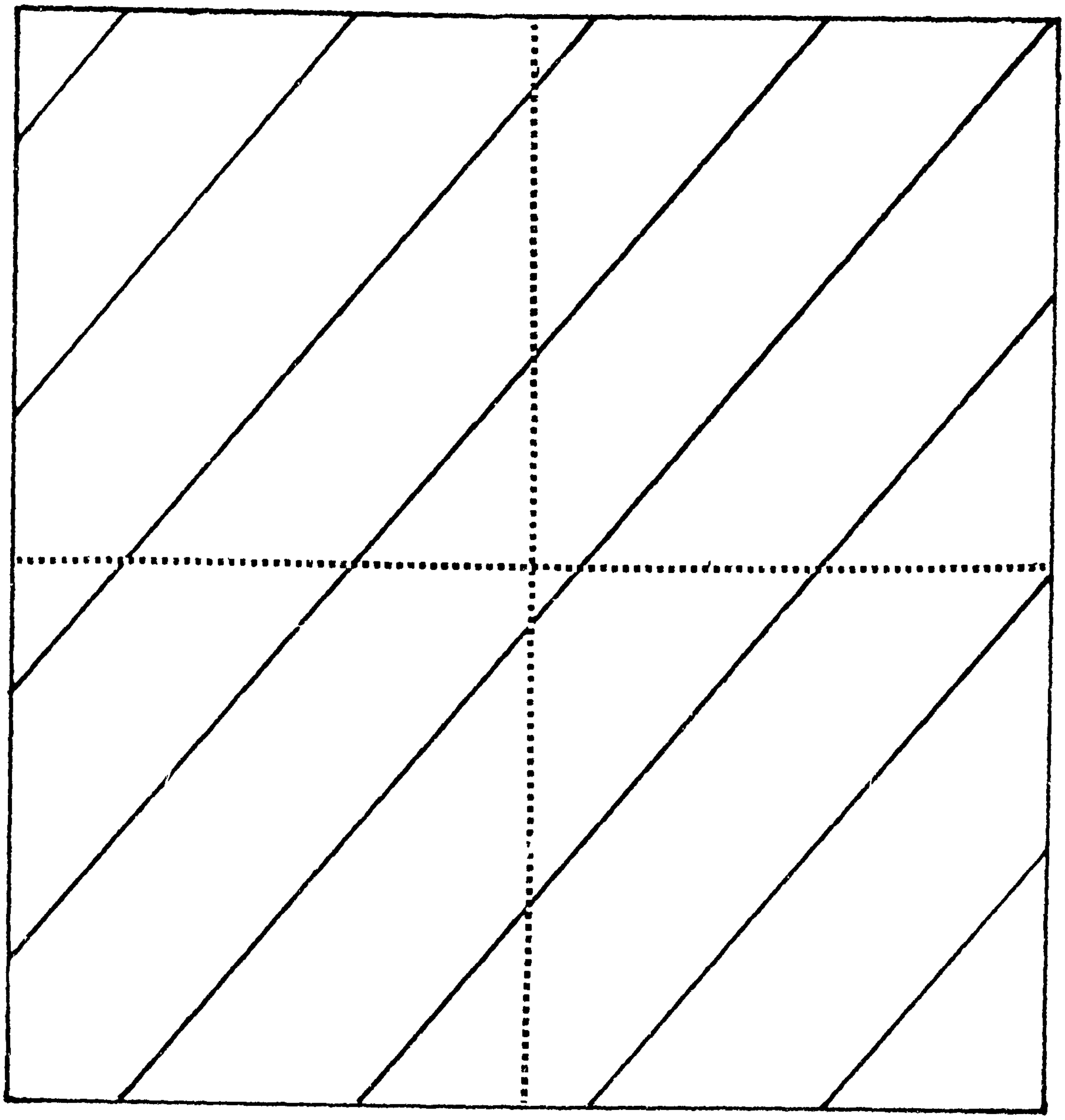
(j) Technical Brochure, "A Sonic Test System for Nondestructively Evaluating Composite Structures", North American Rockwell Corporation, Quality Assurance System, Los Angeles, California

(k) Shurtronic Technical Brochure, "Harmonic Bondtester"

(l) Vadala, E. Th. "Adhesive Bonded Integrity as Evaluated by the Fokker Bondtester", Report No. NAEC-AML-2205 dated 1 June 1965

FIGURE 1

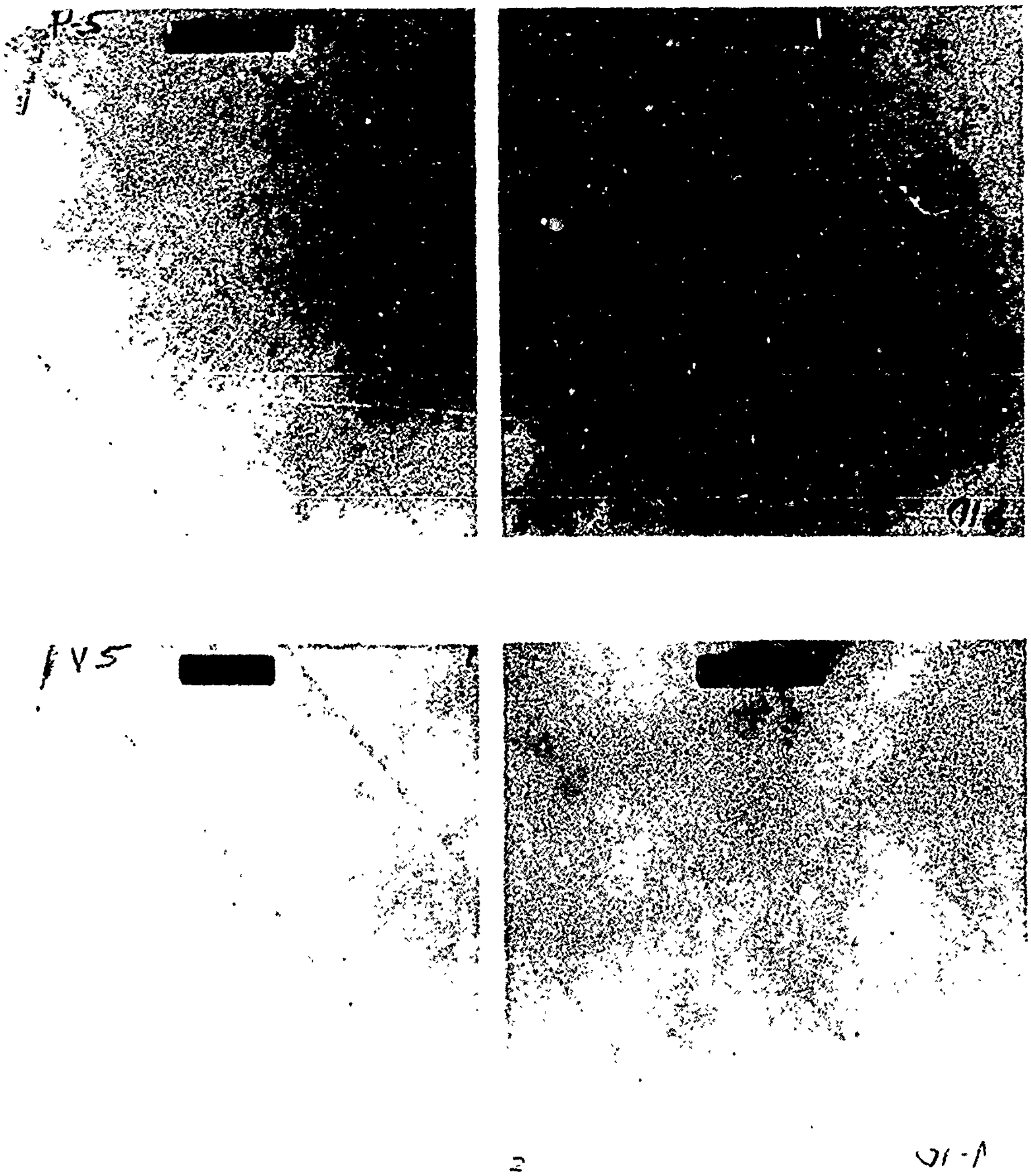
Diagram of Patterns Used for the 18 Inch Square Layup



1 Inch = 3 Inches

FIGURE 2

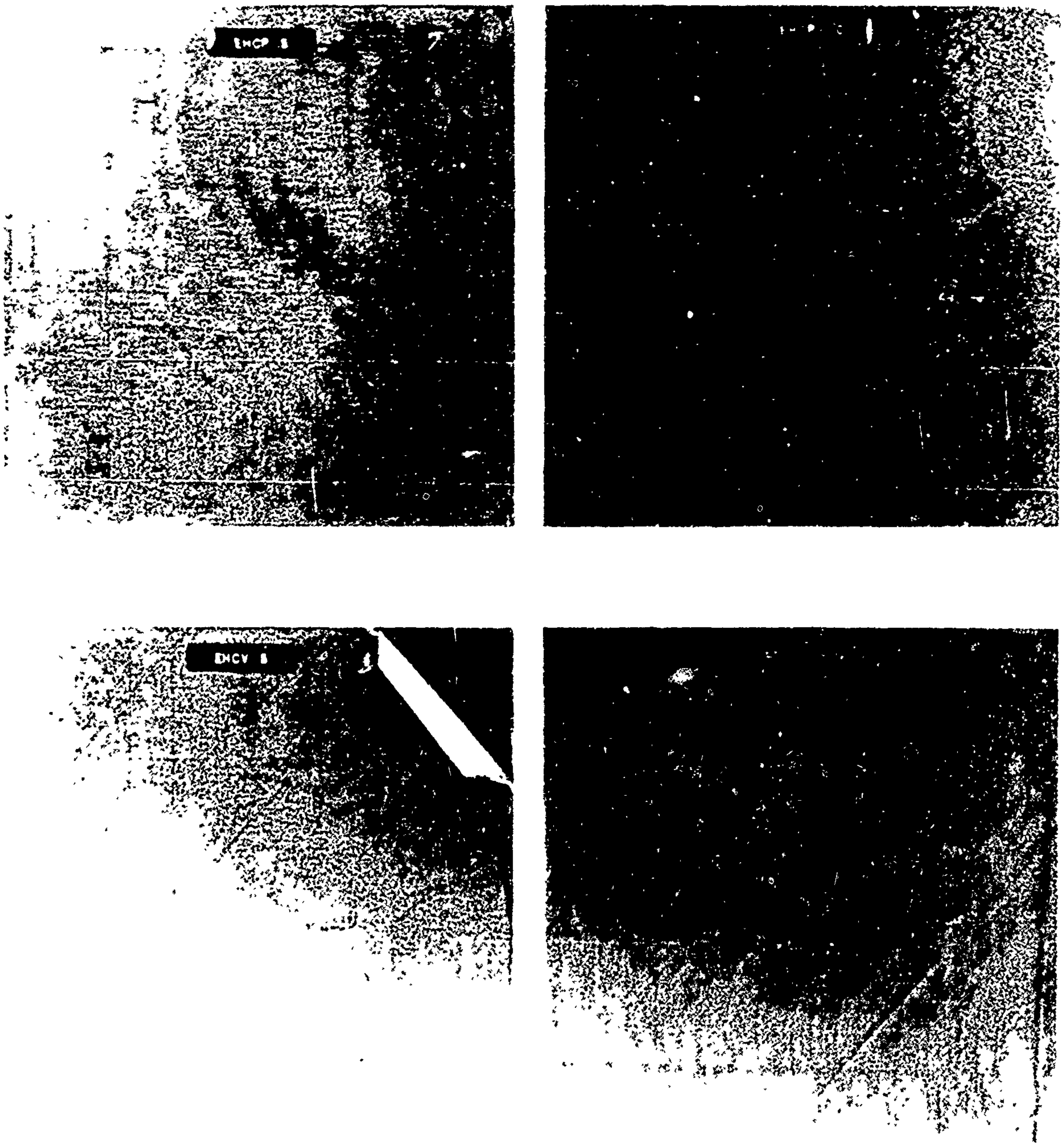
Cured Glass Composites



NOTE: The peel ply is turned back in the EHGP-5 panel.

FIGURE 3

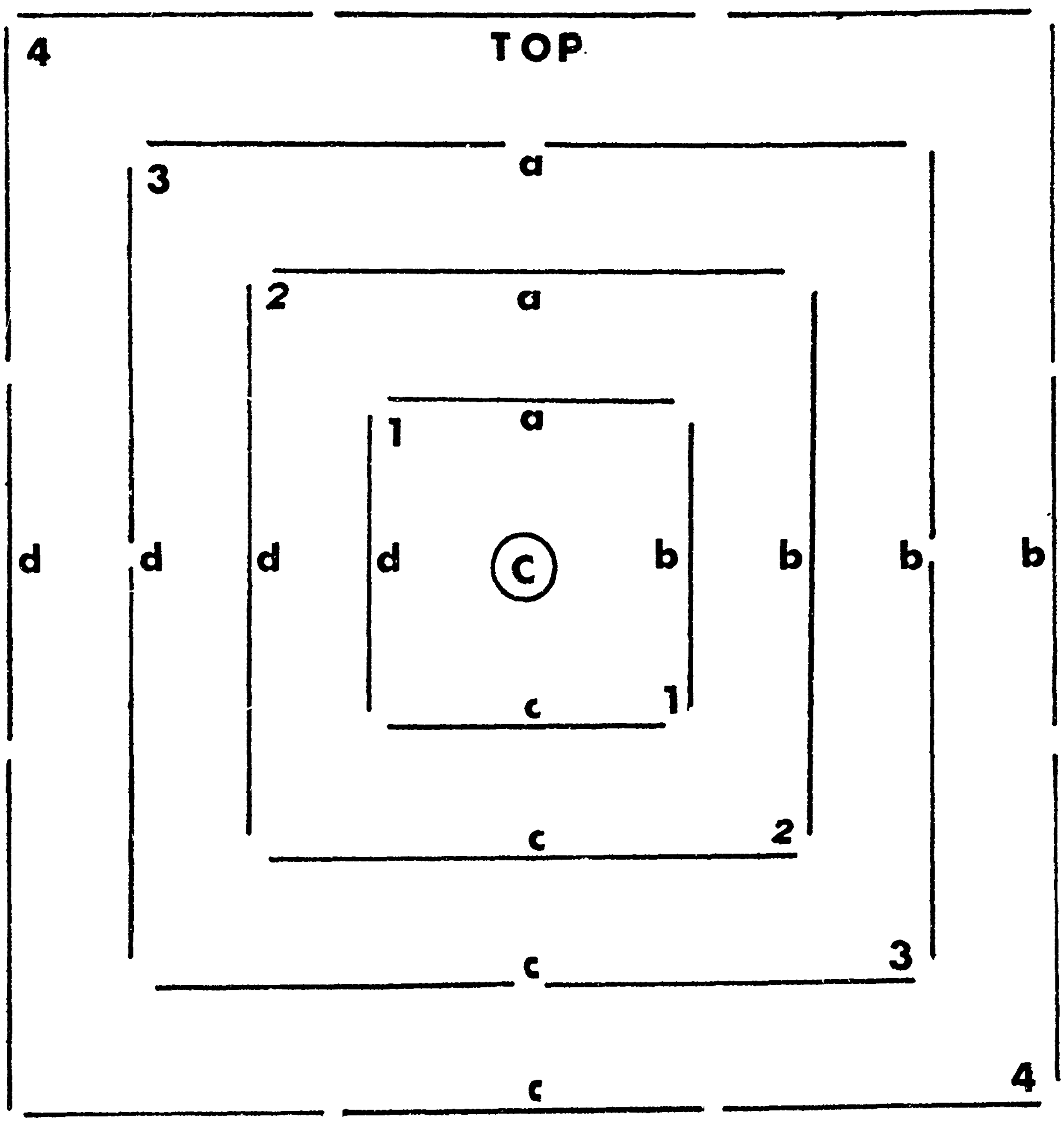
Cured Graphite Composites



NOTE: Peel ply turned back in EHCV-5.

FIGURE 4

Diagram of Plastic Stencil Used to Mark the Composites



3/4 Inch = 1 Inch

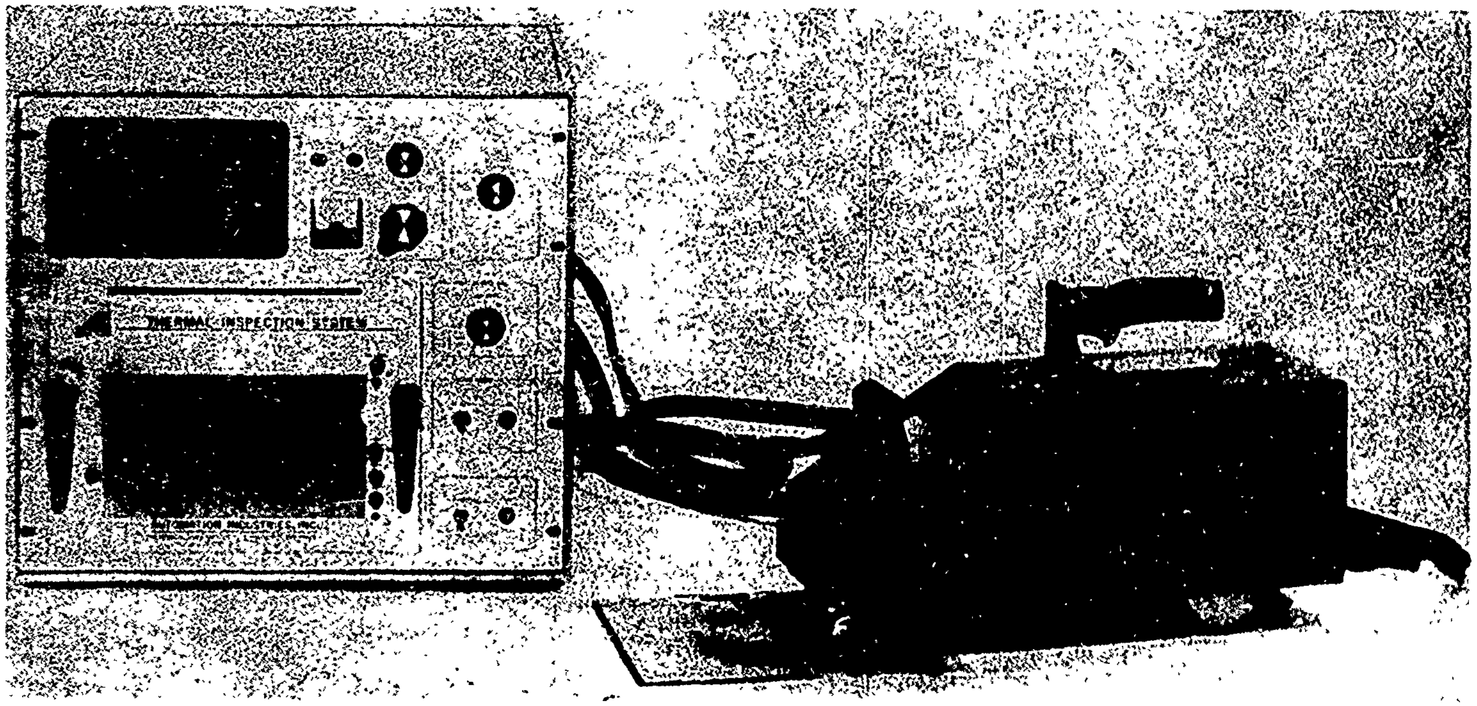


FIGURE 5 Thermal Inspection System

FIGURE 6

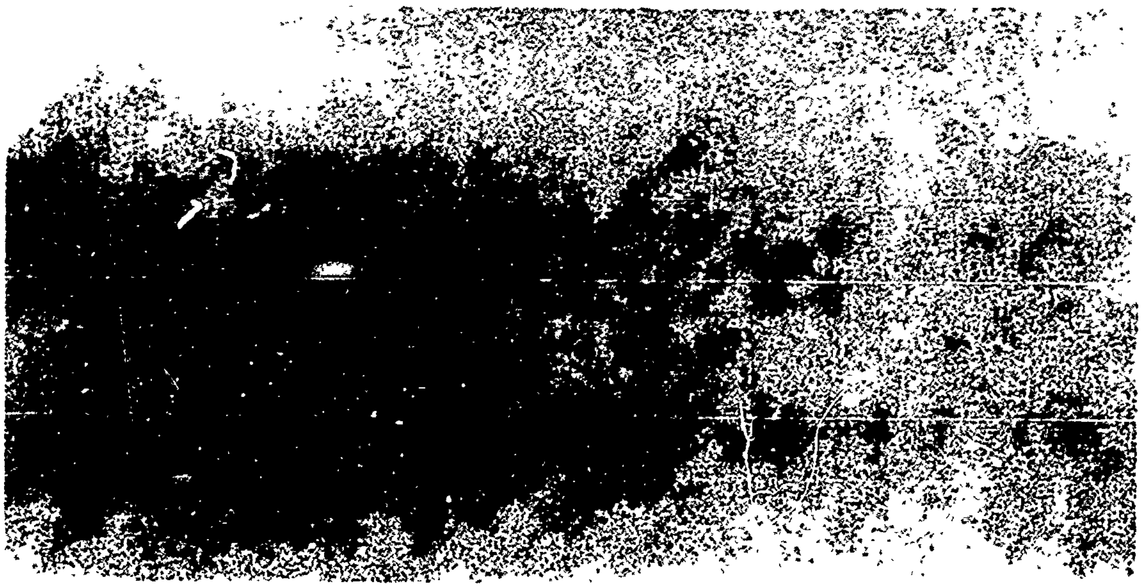
Thermograms of Glass Composites

Level: 0 Volts

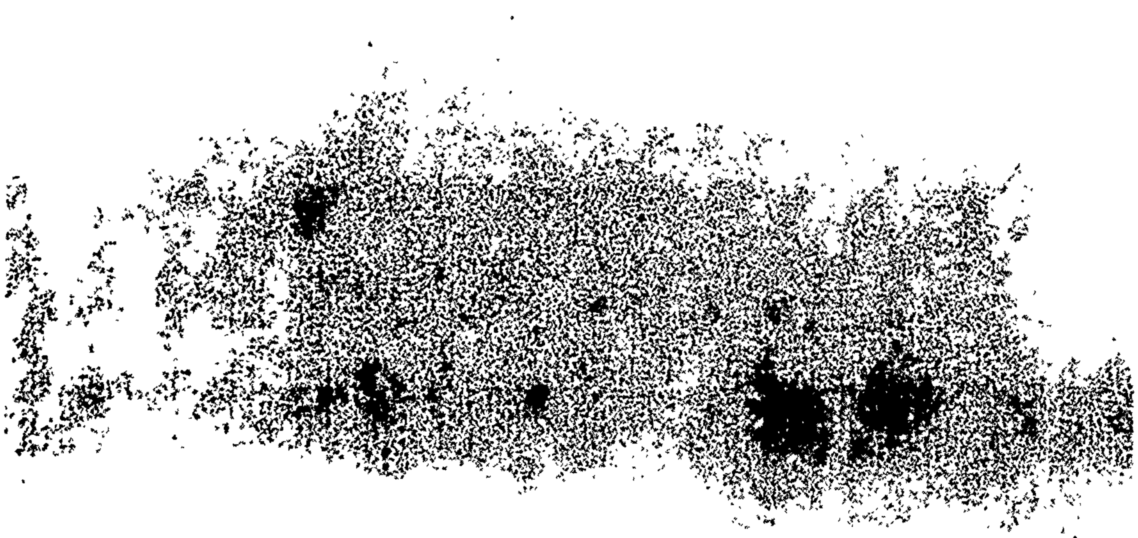
Heat Source Intensity: Max

Sensitivity: 1.0

Normal + Setting



EHGV-10



EHGP-10

FIGURE 7

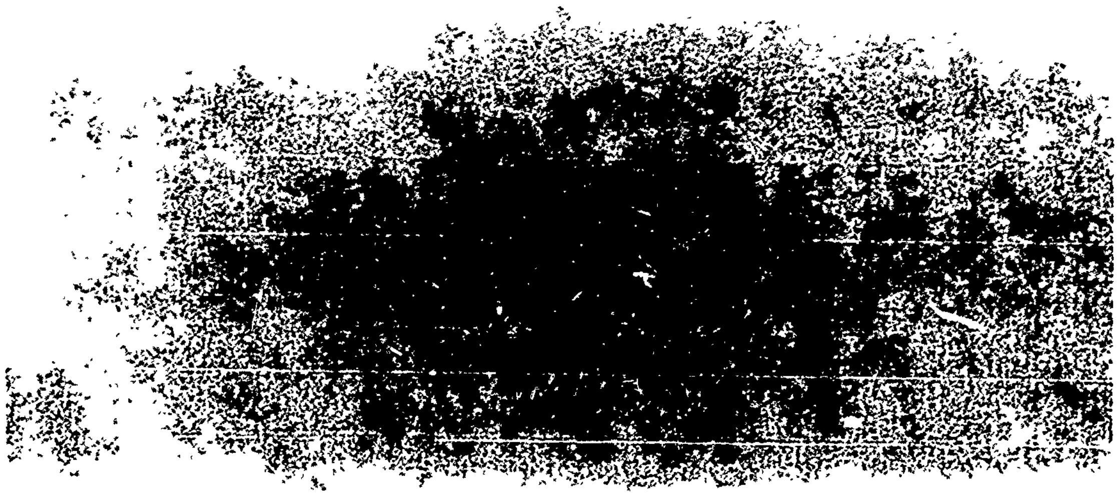
Thermograms of Graphite Composites

Level: 0 Volts

Heat Source Intensity: Max

Sensitivity: 1.0

Normal + Setting



EHCV-10

EHCP-10

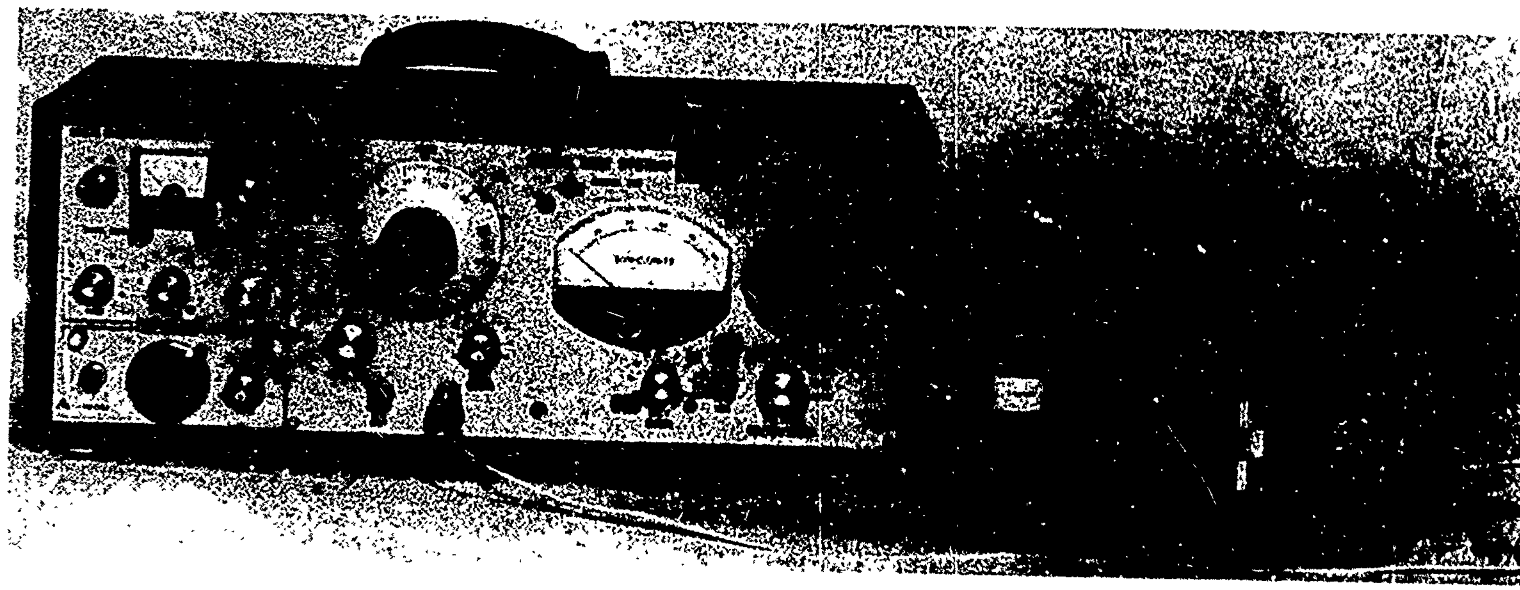


FIGURE 8 Sonic Test System

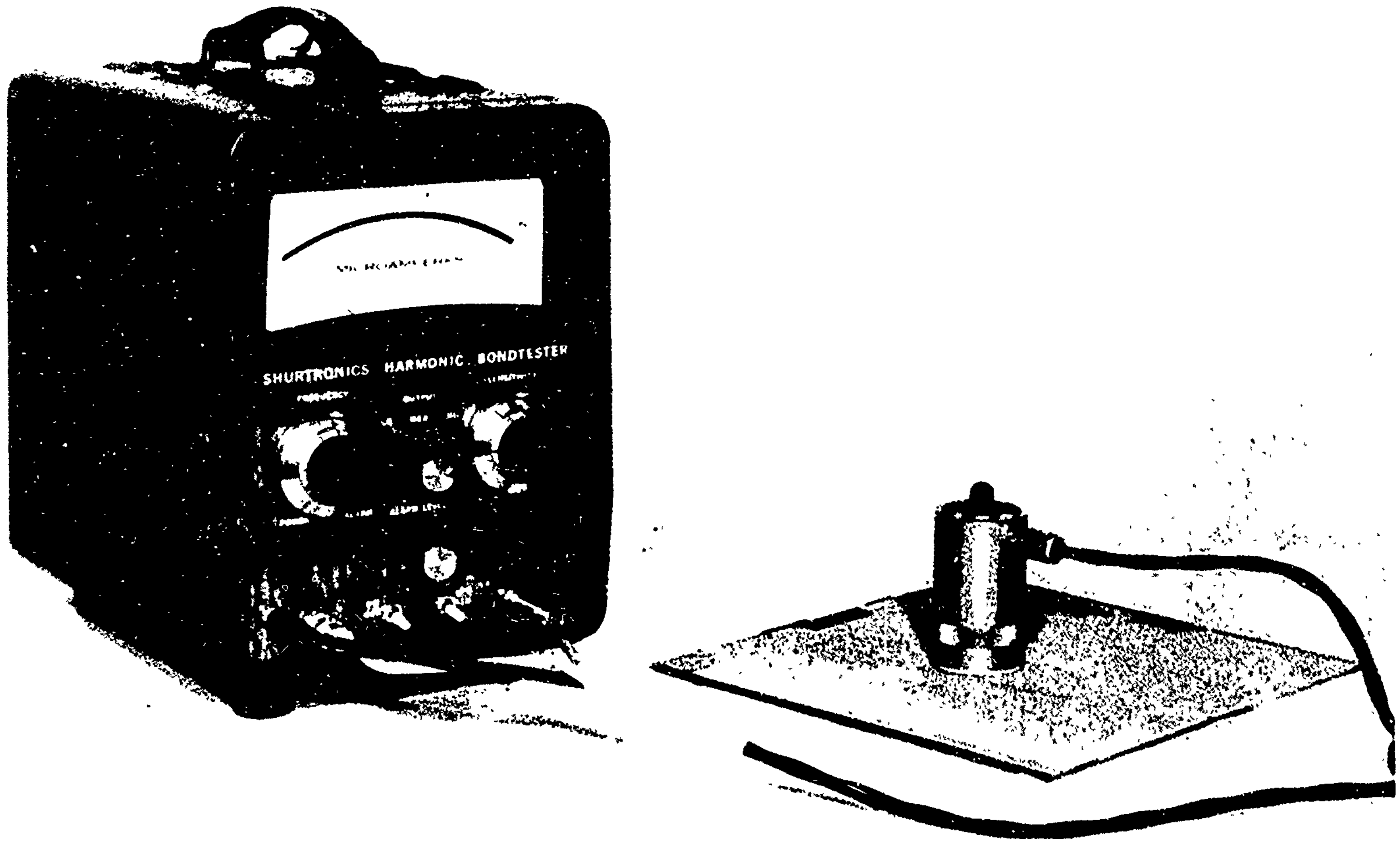


FIGURE 9 Harmonic Bondtester

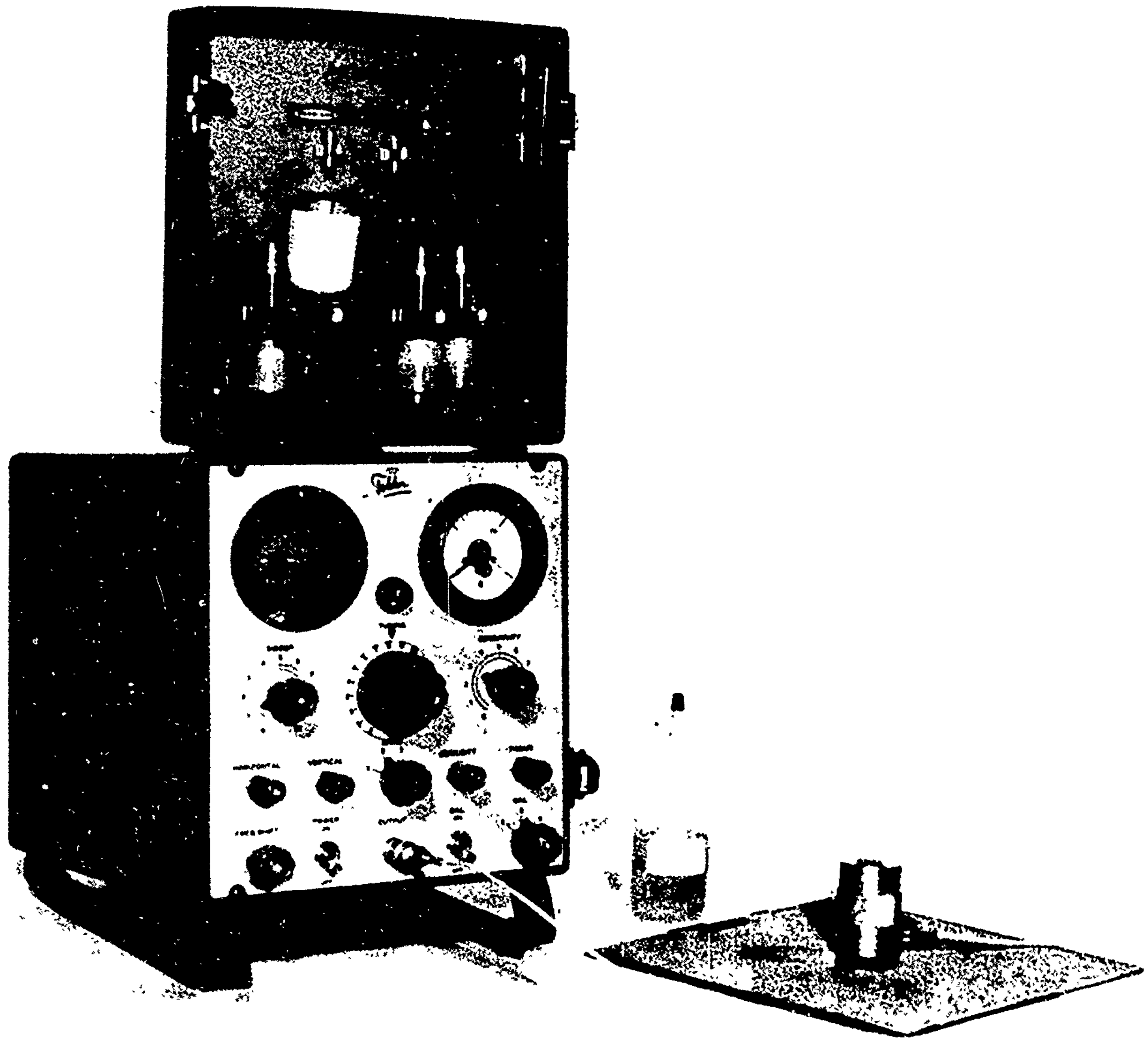


FIGURE 10 Fokker Bondtester

FIGURE 11

Fokker Bondtester, A and B Scale

Sweep:	2.5	Sensitivity:	5
Band:	3	Tuning:	9
Probe:	DN 1012 C-002	Couplant:	BTF 110 40

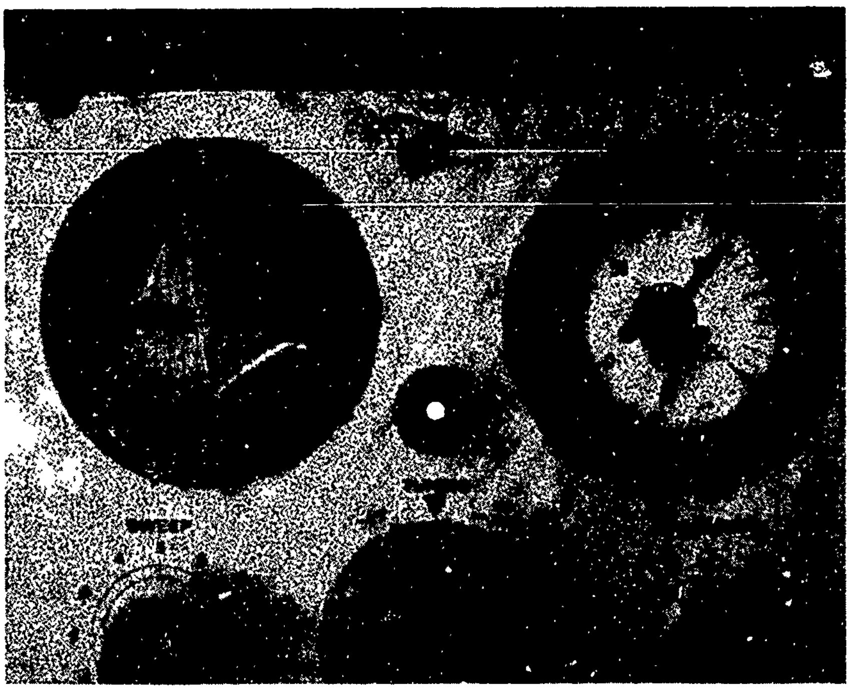
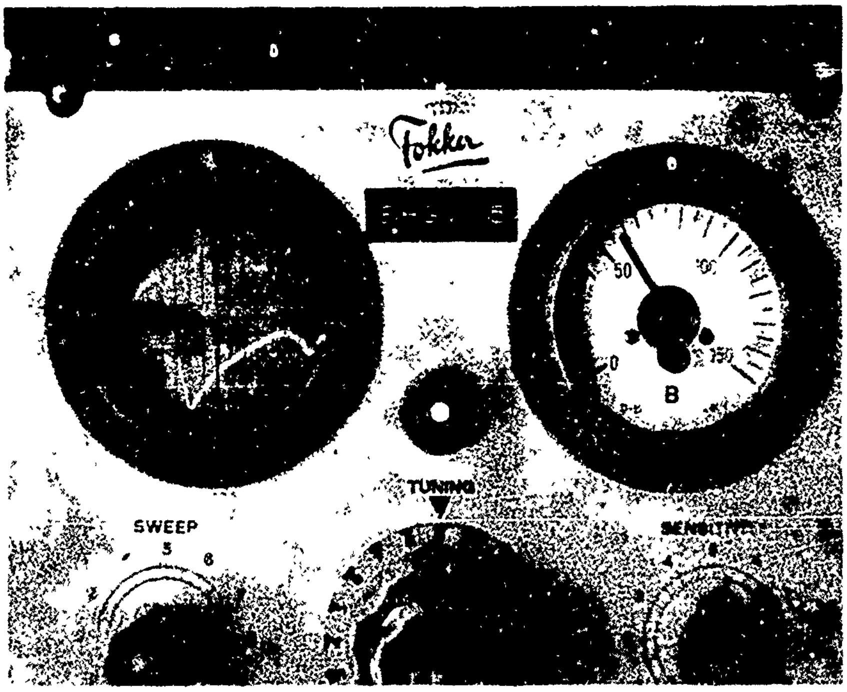


FIGURE 12

Evaluation of Vacuum Cured Glass Composites with Fokker Bondtester



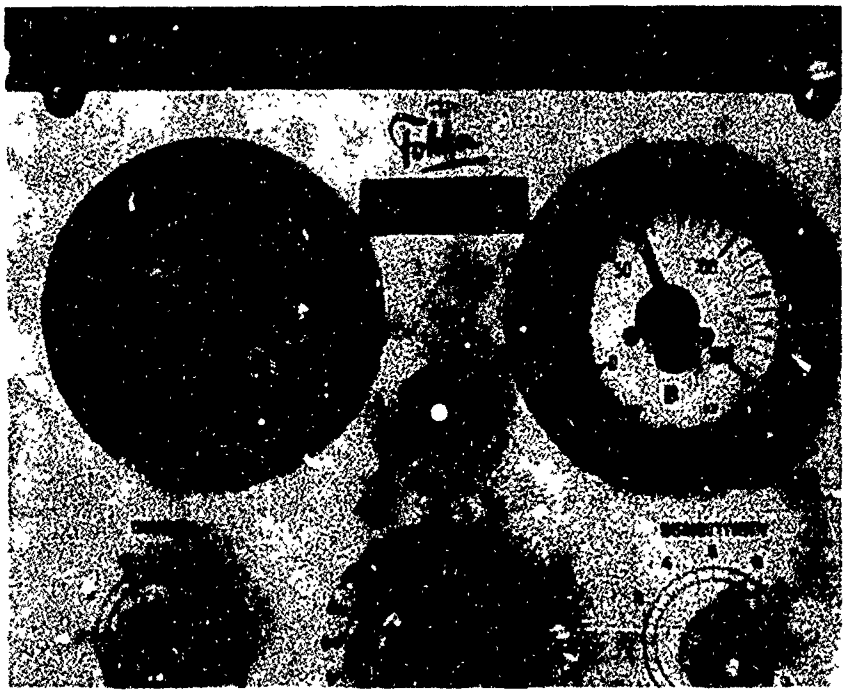
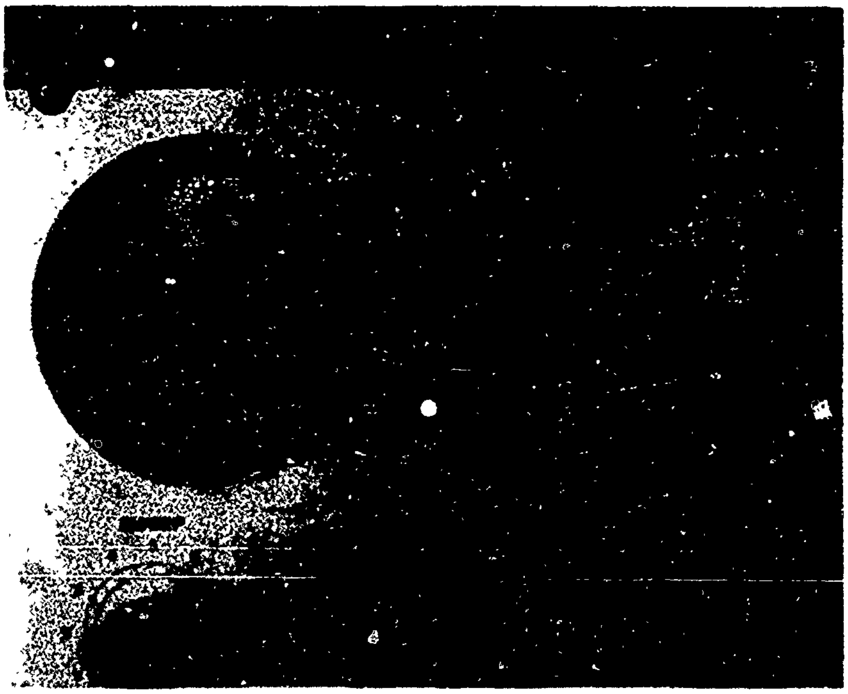


FIGURE 13

Evaluation of Pressure Cured Graphite Composites with Fokker Bondtester



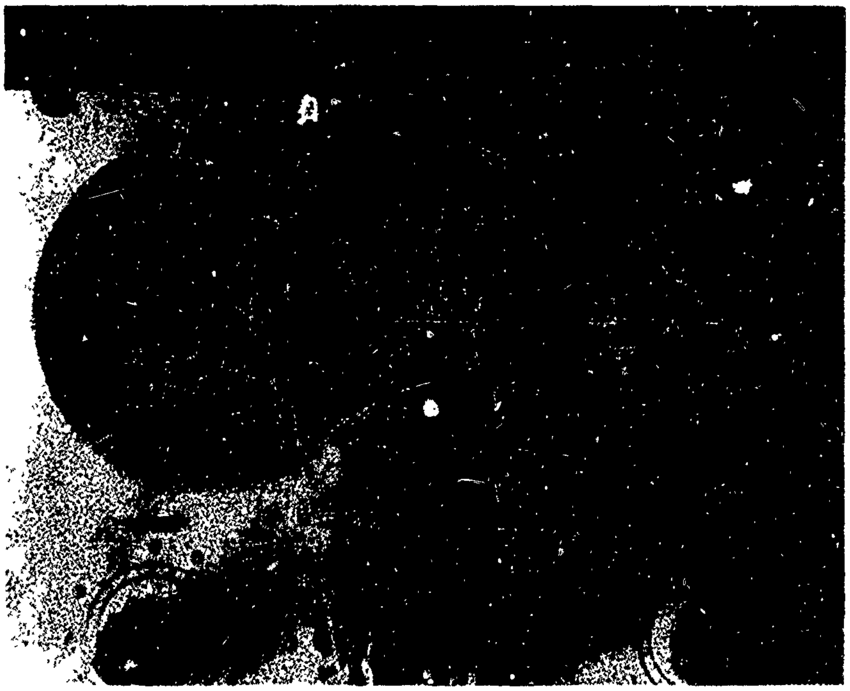
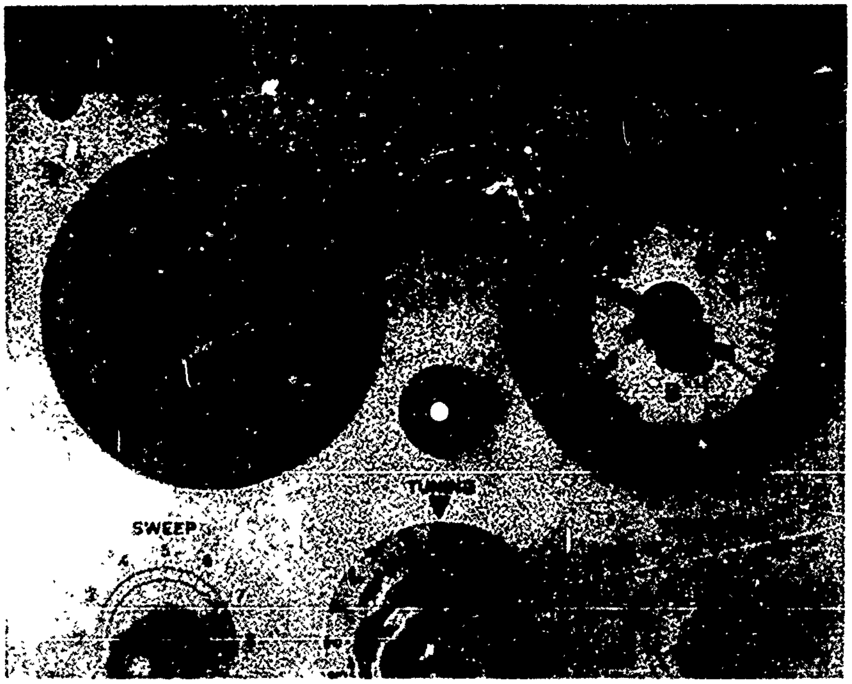


FIGURE 14

Evaluation of Pressure Cured Glass Composites with Fokker Bondtester



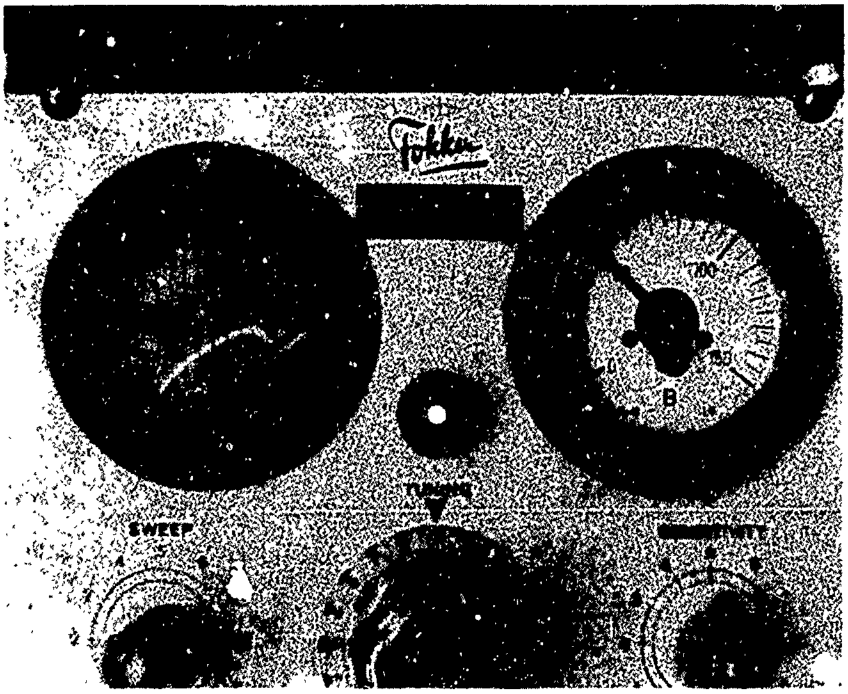


FIGURE 15

Evaluation of Pressure Cured Graphite Composites with Fokker Bondtester

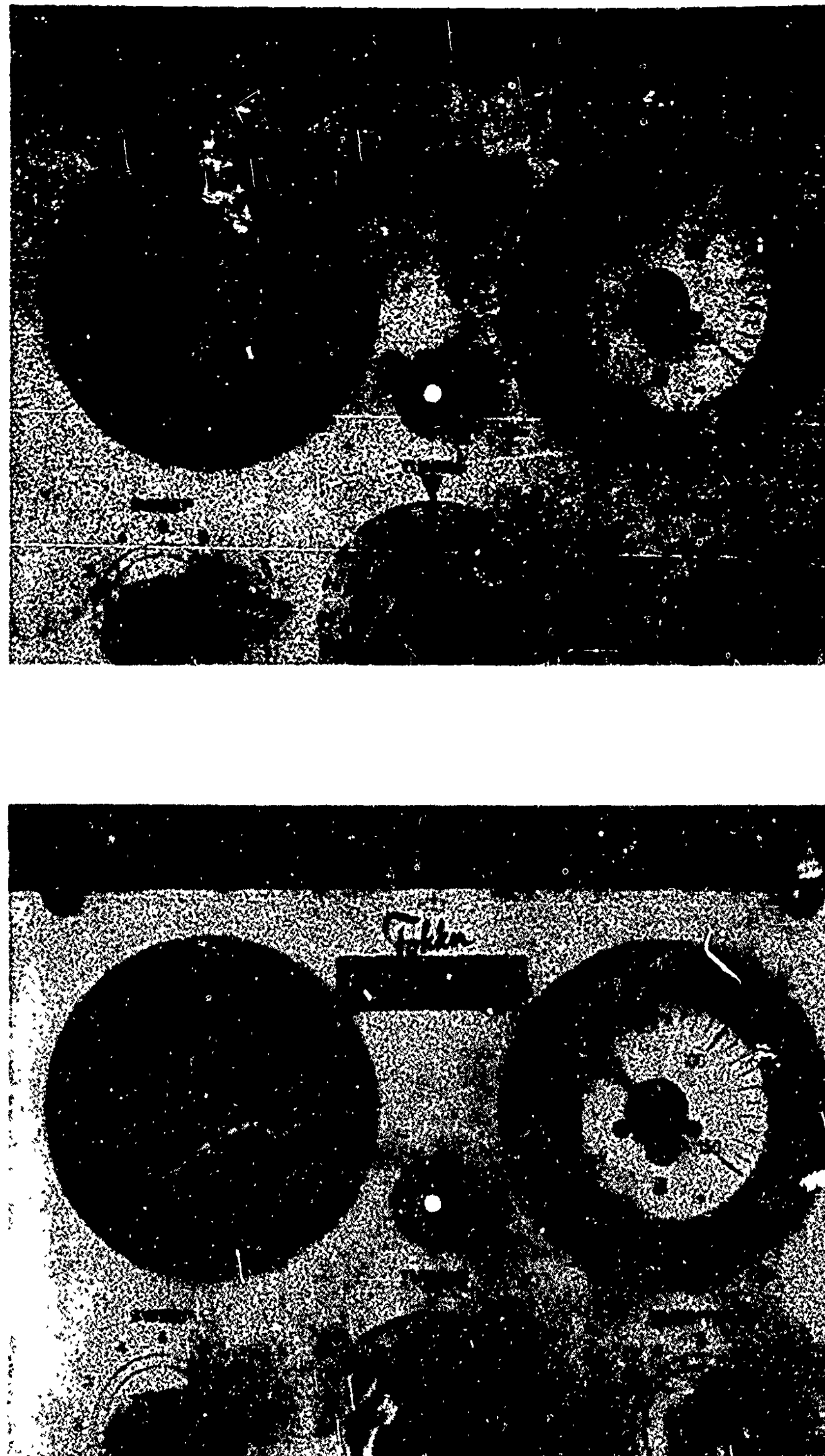
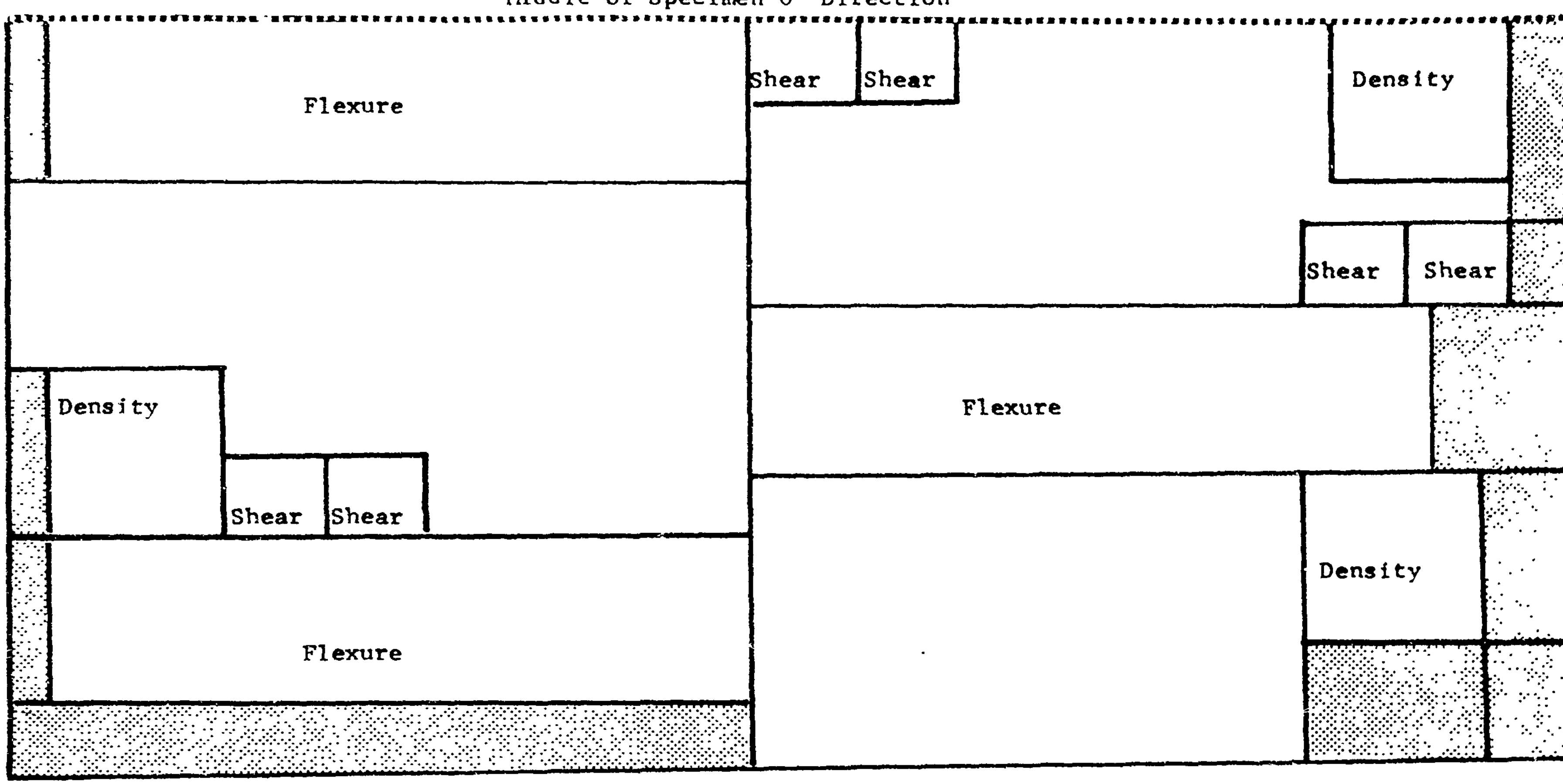


FIGURE 16

Diagram for Test Specimens

Middle of Specimen 0° Direction



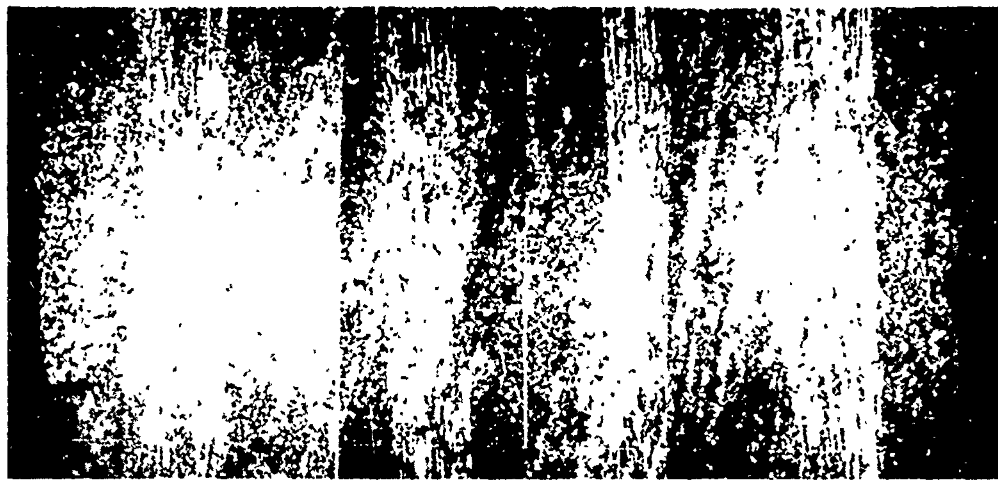
Density Approximately 1 Inch X 1 Inch
Shear - ½ Inch X 0.6 Inch
Flexure - 1 Inch X 4 Inches

FIGURE 16

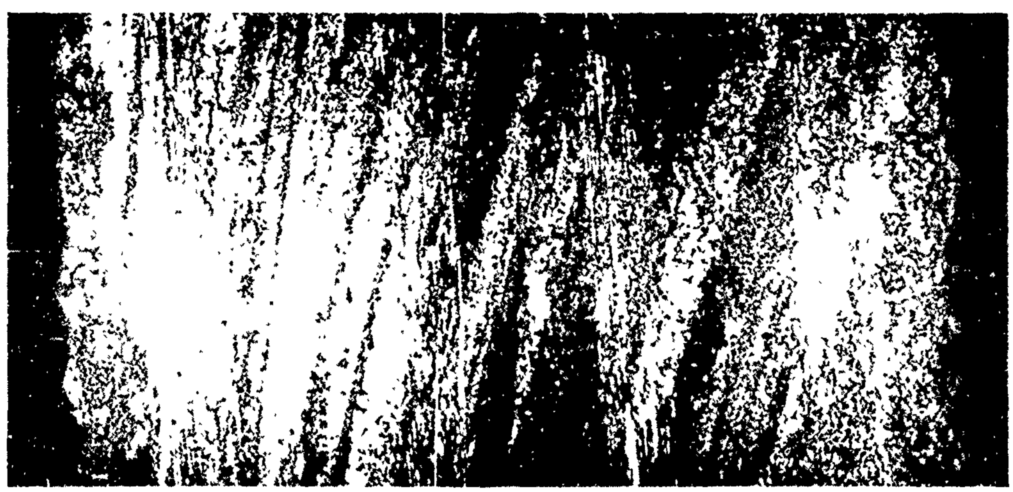
FIGURE 17

Photomicrograph of Cross-Ply Graphite Laminates

EHCV-10 and EHCP-10



EHCV-10



EHCP-10

Magnification, 56X

PAPER #10

THE NONDESTRUCTIVE EXAMINATION OF DISCONTINUITIES IN WELDS BY STEREORADIOGRAPHY

ABSTRACT

A promising approach to the development of a correlation between weld flaws and their effect on mechanical properties is fracture mechanics. This approach necessitates accurate nondestructive evaluation of the weld flaw characteristics.

Stereoradiography, unlike normal incident radiography or ultrasonic inspection, yields a direct three dimensional observation. Stereoradiography involves obtaining an x-ray exposure at two known positions of the specimen with respect to the x-ray tube and viewing the stereo-pair through a stereo-viewer (stereoscope). By accurately measuring the parallax difference between the two exposures resulting from the specimen (or x-ray tube) shift, one may calculate the weld flaw's depth below the plate surface using photogrammetric principles. An accurate and efficient technique for obtaining stereoradiographs was developed in this investigation.

To evaluate this technique, ten pores in a defective weldment were measured three times (at different times). The results were compared to determine how well an observer could reproduce his measurement. The weld was then sectioned and the actual pore depths were measured directly. These results were then compared to the stereoradiographically measured depths to determine the accuracy of the technique. The evaluations were made from a statistical approach and an engineering approach.

It was found that stereoradiography could measure depths within .04 inch of the actual pore depth. Also the average stereoradiographically measured depths were reproducible within .04 inch. In both cases, these appeared insignificantly small for engineering purposes.

Kenneth W. Carlson, Metallurgist
U. S. Army Corps of Engineers
Construction Engineering Research Laboratory
Champaign, Illinois 61820

F. V. Lawrence
Assistant Professor in Metallurgical
Engineering and Civil Engineering
University of Illinois
Urbana, Illinois

NOTE: The opinions or assertions contained in this paper are those of the authors and are not to be construed as official or reflecting the views of the Army Corps of Engineers at large.

PAPER NO. 10

THE NONDESTRUCTIVE EXAMINATION OF DISCONTINUITIES IN WELDS BY STEREORADIOGRAPHY

K. W. CARLSON / F. V. LAWRENCE

1. Introduction

Recently, a considerable volume of research has been performed on the effects that internal discontinuities have on the mechanical behavior of weldments. The presence of flaws together with their size, shape, distribution, orientation and location often deleteriously affects the mechanical properties. A promising approach to predict the properties of flawed welds is provided by fracture mechanics. Knowledge of the flaw geometry and size permits the calculation or estimation of stress intensity factors (K) which in turn allows the prediction of mechanical properties.

To facilitate the application of fracture mechanics, accurate nondestructive evaluation (NDE) techniques must be developed. Present NDE techniques are not entirely adequate for obtaining accurate measurements of flaw characteristics. The most common techniques, radiography and ultrasonics, offer only two dimensional observation of the weld. Stereoradiography, on the other hand, permits direct three dimensional observation, thus, providing a much better visualization of the spatial characteristics of flaws. The technique entails viewing a stereo-pair (which is two radiographs taken at two known positions of the specimen with respect to the x-ray tube) through a stereo-viewer (stereoscope). Depth calculations of weld flaws may be obtained from parallax measurements on the stereo-pair and the application of photogrammetric principles. If it is possible to distinguish and identify the top and bottom of a flaw, its through-thickness dimension can also be measured.

Stereoradiography has been used since the early 1950's in the medical profession, but it has been applied very little to nondestructive examination of materials. Hallert[1,2] made one of the initial attempts to derive a parallax formula for the calculation of depth. Hallert's technique, however, involved locating the principal points of the x-ray source (vertical projections of the source) on the film and using these as the origins of two coordinate systems. This technique does not appear practical for nondestructive examination because accurate location of the principle points is quite difficult.

Later McMaster[3] proposed stereoradiography as an NDE technique. McMaster secured a fiducial marker to the bottom of a specimen and shifted the source between exposures. The marker was assumed to be on the film plane and not to contribute any parallax. The primary disadvantage of this is that to avoid upsetting the marker when the film is changed between exposures, clearance between the specimen and the film is necessary which may give the marker an appreciable parallax, thus, becoming the source of significant error.

In 1963, Singh[4,5] derived a parallax equation for a specimen with a fiducial marker on the top of the plate. His equation accounted for the parallax of the marker as well as the pore; therefore, the depth was dependent on the parallax difference between the marker image and the image of the defect to be measured. This development was applied primarily to medical radiography. It is the principles of Singh's work which was applied to nondestructive evaluation of flawed materials.

In 1966, McNeil[6] developed an equation which like Singh's considered the parallax of both the marker and the defect and applied it to a specimen with the marker mounted on the bottom of the specimen like McMaster. McNeil's parallax equation was identical to Singh's except that it was developed for the marker located at the bottom of the specimen. Also, he discussed accurate calibrations of distance between source and image and alignment of the source directly over the image. Moreover, McNeil evaluated the effect of penumbra on the accuracy of measurements and found that the magnitude of this error is small. This technique is easiest to apply when the marker is located on the top of the specimen which, in fact, is the technique of Singh.

The purpose of this investigation was to develop a technique of obtaining accurate depth measurements from stereoradiographs of flawed weldments. The results yielded by the technique were then analyzed and evaluated in both a statistical and engineering sense to appraise the applicability of stereoradiographic depth measurement to nondestructive evaluation of flawed materials and, in particular, weldments containing discontinuities.

2. Procedure

The welded specimen was prepared by conventional techniques during which porosity was created in a one inch plate. The weld reinforcement was removed by machining, and the plate was ground to give the surface a smooth finish.

Parallax Equations

The derivation of the parallax equations[5] is based upon the geometry of the experimental technique shown in Figures 1 and 2. It is assumed that the x-rays emanate from a point source, travel in straight lines, and that the x-ray tube is positioned in such a way that the central rays are perpendicular to the image plane (x-ray film). Although it is impossible to attain these conditions exactly, the arrangement that was used approached them. The focal spot of the source was .3 centimeters which is effectively a point source with a 30 inch tube-film distances used in this investigation.

A marker of known thickness, T_m, and a defect whose depth is unknown cast their shadows on the x-ray film at m_1 and n_1 during the first exposure

and at m_2 and n_2 during the second exposure. By considering similar triangles in Figure 1, the distance between the flaw and marker (ΔD_{mn}) has been found[5] to be

$$\Delta D_{mn} = \frac{\Delta S_{mn} D_m (A - D_m)}{AS - \Delta S_{mn} D_m} \qquad (1)$$

where ΔD_{mn} $D_m - D_n$

ΔS_{mn} $S-s$ = parallax difference between marker and defect

S = parallax for M (marker)

s = parallax for N (defect)

D_m = height of M above the film

D_n = height of N above the film

A = film-to-tube distance

The actual parallax difference is measured as shown in Figure 2. Thus,

$$\Delta S_{mn} = R_m - R_n$$

where R_m = parallax measurement of M

R_n = parallax measurement of N

It was assumed that the shadow of the marker was cast by the top of the marker; therefore, the depth of the defect is

$$D_{nt} = \Delta D_{mn} - T_m \qquad (2)$$

where D_{nt} = distance of the flaw beneath the plate surface. It should be noted that this is only an assumption and that the shadow may have indeed been cast from some point within the midthickness of the marker. Work is presently being performed to determine the actual point which is representative of the marker shadow.

Obtaining the Stereoradiographs

To obtain the greatest detail, a high contrast, fine grain x-ray film was used. If was found[7] that detail was optimized by using lower kilovoltage (KV) values and long exposure times. To obtain the best image, good contact between the film and intensifying screens in the cassette is necessary. If the lead intensifying screens are not in close contact with the x-ray film, electrons excited by the x-rays scatter excessively and the resolution is reduced. To minimize this reduction, rigid stainless steel frame cassettes were used.

Three lead markers of thickness (T_m) .060 inch were secured to the top of the plate with masking tape in a line parallel to the direction of the weld and will be referred to as M1, M2, and M3. The plate with the

markers was placed on a wooden U-shaped frame of known thickness which was slightly larger than the thickness of the cassettes. Thus, the cassette could be slipped in and out from underneath the weld plate (see Figure 3). This assembly was placed on a lead surfaced table to minimize the back-scatter of x-rays.

Rather than shift the x-ray tube, the same effect was more accurately produced by moving the specimen. The shift was accomplished with the aid of precisely machined guides and stops (Figure 3). Two exposures were made with the assembly shifted alternately from right to left. Each exposure was appropriately marked to designate the exposure position.

To yield the maximum "stereo effect" each exposure of the stereo-pair must have the same density and quality. For this reason both exposures of the stereo-pair were made with identical x-ray tube conditions and exposure times. In addition, both exposures of the stereo-pair were developed on the same developing hanger so that their developing conditions were identical.

Parallax Measurements

The parallax observations and measurements were made with a mirror stereoscope, as shown in Figure 4. The stereoscope is equipped with 3X oculars and a parallax bar which is calibrated to hundredth of a millimeter.

Prior to observing the stereo-pair, they were mounted with the right and left exposures under the right and left eyepiece and secured with tape to an illuminator in a position such that the comfort of stereo viewing was maximized. Extreme care was needed to adjust the film separation on the illuminator properly so as to accommodate to the observer's eyes.

The parallax measurements of various points on the stereoradiograph were obtained with the use of the parallax bar. To obtain a statistically significant average value of parallax, three measurements were taken of every marker and flaw. In most cases the parallax measurements for a particular flaw were not made consecutively so that observer bias was minimized. From equation (1), it can be seen that the actual value of the parallax was not important, but that the parallax difference (ΔS_{mn}) between flaw and marker was the important value (Figure 2). A computer program was developed which calculates the depths of all the measured flaws using equations (1) and (2).

Test of Reproducibility and Accuracy of the Stereoradiographic Measurements

The stereoradiographic technique was tested to evaluate its reproducibility by an observer and its accuracy with respect to the actual depths. In this series of tests a stereo-pair was made of a weldment containing scattered porosity. The stereo-pair was observed and parallax measurements were obtained, three times, for ten pores by the observer (these will be referred to as Replications #1 and #2). From the parallax measurements, depths were calculated.

After the stereoradiographic observations, the weld was sectioned, and in the porous region that was considered for stereoradiographic measurements, the actual defect depths were measured on macro-photographs. An evaluation of how accurately stereoradiography could measure pore depths was made from these direct depth measurements.

3. Results, Analysis and Discussion

As stated previously, the intent of these tests was to evaluate the ability of an observer to repeat his measurements and the degree of accuracy with which the stereoradiographically measured depths agree with the actual depths. The results of these tests are given in Table 1.

Replication Tests

The three Replications were compared to evaluate the reproducibility of the depth measurements by an observer. To analyze the reproducibility of the measurements an analysis of variance utilizing an "F-test" was performed on the data.[8] The F-test revealed that there is a statistically significant difference (variation beyond expected experimental error) between Replications #1 and #2. (This fact does not necessarily mean, however, that the ability to repeat the measurements was insufficient for engineering application of the stereoradiographic technique.)

On the other hand, Replications #1 and #3 revealed no significant difference between them. A comparison of Replication #2 and #3 also revealed no significant difference. Thus, Replications #1 and #2 proved to be the extremes in this limited experiment. The promise of the technique is, thus, exemplified by the fact that two of the three Replications agreed within statistical variation.

To analyze the accuracy of the stereoradiographic technique, it is necessary to compare the measured flaw depths to the actual flaw depths. It was found that the average differences between measured and actual depths were .003 inch, .040 inch, and .018 inch for Replications #1, #2 and #3 respectively.

To evaluate how well the measured depth correlated to the actual depths in a statistical sense a t-test which is similar to the F-test was used.[8] A summary of the t-test is shown in Table 2. It was found from the t-test that there was no significant difference between the actual depths and measured depths in Replication #1 and #3 while there was a significant difference in Replication #2. Since the standard deviations are nearly the same, the consistency of the measurements were similar. Thus, the error might have been a slightly misaligned member of the stereo-pair in the second measurement.

The discussion until now has considered the results of the investigation in a statistical sense. The data have been viewed in light of

expected experimental error. However, engineering applications of stereoradiography can tolerate error beyond experimental error before the final results are significantly changed.

At the outset of this work, it was asserted that stereoradiography was a most promising technique in nondestructively examining weldments containing flaws and obtaining quantitative depth measurements. The results of the stereoradiographic examination could be used in fracture mechanics relationships which would predict mechanical properties from the measured defect sizes and geometries.

Two of the significant results of this study are the average differences and standard deviations reported in Table 2. The standard deviations can be seen to be nearly the same which, in fact, indicates a consistency between the three observations. The average differences for Replications #1, #2, and #3 are .003, .040, and .018. Variations of these magnitudes in a one inch plate should not significantly affect the value of the stress intensity factor (K) calculated from fracture mechanics equations.

Although the variation between Replications #1 and #2 is significant, statistically, it is tolerable for engineering application for the same reason that is given above; that is, variations of .040 inch in depth will not significantly change calculated K values or the calculated mechanical properties to be expected. The average variation between Replications #1 and #2 as seen in Table 2 is .033 inch.

4. Conclusions

From this investigation, stereoradiography has proven to be a potentially valuable nondestructive examination technique. Not only does it permit one to view the spatial distribution and orientations of the defects in the weld, but it also allows one to accurately measure the depth of the defects below the surface. Such results could permit the establishment of more objective nondestructive examination standards.

Statistical analysis revealed that the variation between Replications #1 and #3 and the actual depths were insignificant (within experimental error) while Replication #2 varied significantly from the actual depth. Also the variation between Replications #1 and #2 and between Replication #2 and the actual depths are statistically significant; however, the magnitude was sufficiently small that the variation was insignificant for engineering application which can tolerate more variation.

From these tests, it might be said that a skilled observer may measure depths within .040 inch of the actual depths and also within .040 inch of a second replication.

Stereoradiography has three primary advantages as a nondestructive examination tool:

1) Unlike most other NDT techniques, it allows a three, rather than two, dimensional observation of the internal discontinuities in the weld.

2) A skilled stereoscopic observer may obtain accurate depth measurements by applying photogrammetric principles as presented in this investigation.

There are several limitations to the stereoradiographic technique which must be minimized in order to get more accurate results:

1) Poor resolution in the exposures makes accurate parallax measurements difficult. The defects can be measured only as well as they can be seen.

2) If the flaw is large and appears as a "blob", it is difficult to make accurate parallax measurements. The defect should be well defined or have some particular characteristic such as a corner to measure.

3) The stereoscopic observer must be skilled and his eyes conditioned for stereo viewing through practice.

4) The exposures must be precisely aligned, which is difficult because the eyes tend to strain themselves to accommodate to stereo viewing when misalignment is small. Misaligned stereoradiographs give distorted parallaxes.

Future planned work to develop automation techniques should remove the majority of these limitations.

Kenneth W. Carlson, Metallurgist
U.S. Army Corps of Engineers
Construction Engineering Research Lab
Champaign, Illinois 61820

F. V. Lawrence
Assistant Professor in Metallurgical
Engineering and Civil Engineering
University of Illinois
Urbana, Illinois

References

1. Hallert, B., "The Basic Principles of X-ray Photogrammetry," Transactions of the Royal Institute of Technology, Stockholm, Sweden, Nr. 123, 1958.

2. Hallert, B., X-ray Photogrammetry, Basic Geometry and Quality, Amsterdam: Elsevier Publishing Company, 1970.

3. McMaster, R.C., Nondestructive Testing Handbook, New York: The Ronald Press Company, 1963, pp. 20.46-20.49.

4. Singh, R.S., "Stereoradiography and Allied Techniques in the Field of Medical Sciences," Masters of Engineering Thesis, University of Roorkee (India), 1963.

5. Singh, R.S., "Radiographic Measurements," Photogrammetric Engineering, 1970, pp. 1137-1146.

6. McNeil, G. T., "X-Ray Stereo-Photogrammetry," Photogrammetric Engineering, 1966, pp. 993-1004.

7. Carlson, K.W., Kruzic, R.W., Lawrence, F. V., Jr., and Radziminski, J.B., "The Introduction and Characterization of Discontinuities in High Strength Steel Weldments," Interim Report, Department of the Army, Construction Engineering Research Laboratory, Champaign, Illinois.

8. Carlson, K.W., The Nondestructive Examination of Internal Weld Flaws by Stereoradiography, Master's Thesis, (University of Illinois, June 1971).

TABLE 1

FLAW DEPTHS MEASURED WITH

THE STEREORADIOGRAPHIC TECHNIQUE AND

THE ACTUAL DEFECT DEPTHS

Defect Number	Average Calculated Depths From Stereoradiographic Measurements* (inches)			Actual Depth+ (inches)
	Replication #1	Replication #2	Replication #3	
1	.36	.31	.34	.33
2	.38	.39	.37	.39
3	.34	.31	.33	.36
4	.38	.37	.35	.39
5	.42	.35	.40	.39
6	.47	.41	.45	.43
7	.29	.27	.30	.33
8	.38	.33	.34	.38
9	.31	.27	.30	.33
10	.18	.13	.18	.21

* Each depth reported is the average of three parallax measurements.

\+ Measured from the surface of the plate to the top extremity of the pore.

TABLE 2

RESULTS OF THE t-TEST ANALYSIS FOR COMPARING THE ACTUAL DEPTHS TO AVERAGE CALCULATED DEPTHS

Defect Number	Evaluated Quantity	Rep #1	Rep #2	Rep #3
1		- 0.03	0.02	- 0.01
2		0.01	0.00	0.02
3		0.02	0.05	0.03
4	Actual Depth -	0.01	0.02	0.04
5	average calculated	- 0.03	0.04	- 0.01
6	depth (from stereo-	- 0.04	0.02	- 0.02
7	radiographic	0.04	0.06	0.03
8	measurements) = d	0.00	0.05	0.04
9		0.02	0.06	0.03
10		0.03	0.08	0.03
	Sum of Difference Σd	.03	.40	.18
	Average Difference $\bar{d}$	.003	.04	.018
	Sum of the Difference Squared $(\Sigma d)^2$	.0009	.1600	.0324
	Sum of Each Difference Squared Σd^2	.0069	.0214	.0078
	Standard Deviation $S = \sqrt{\frac{n\Sigma d^2 - (\Sigma d)^2}{n(n-1)}}$	.0275	.0245	.0225
	$t = \frac{\bar{d}}{S/\sqrt{n}}$	.35	5.16	2.53
	Significant t Value	2.82	2.82	2.82

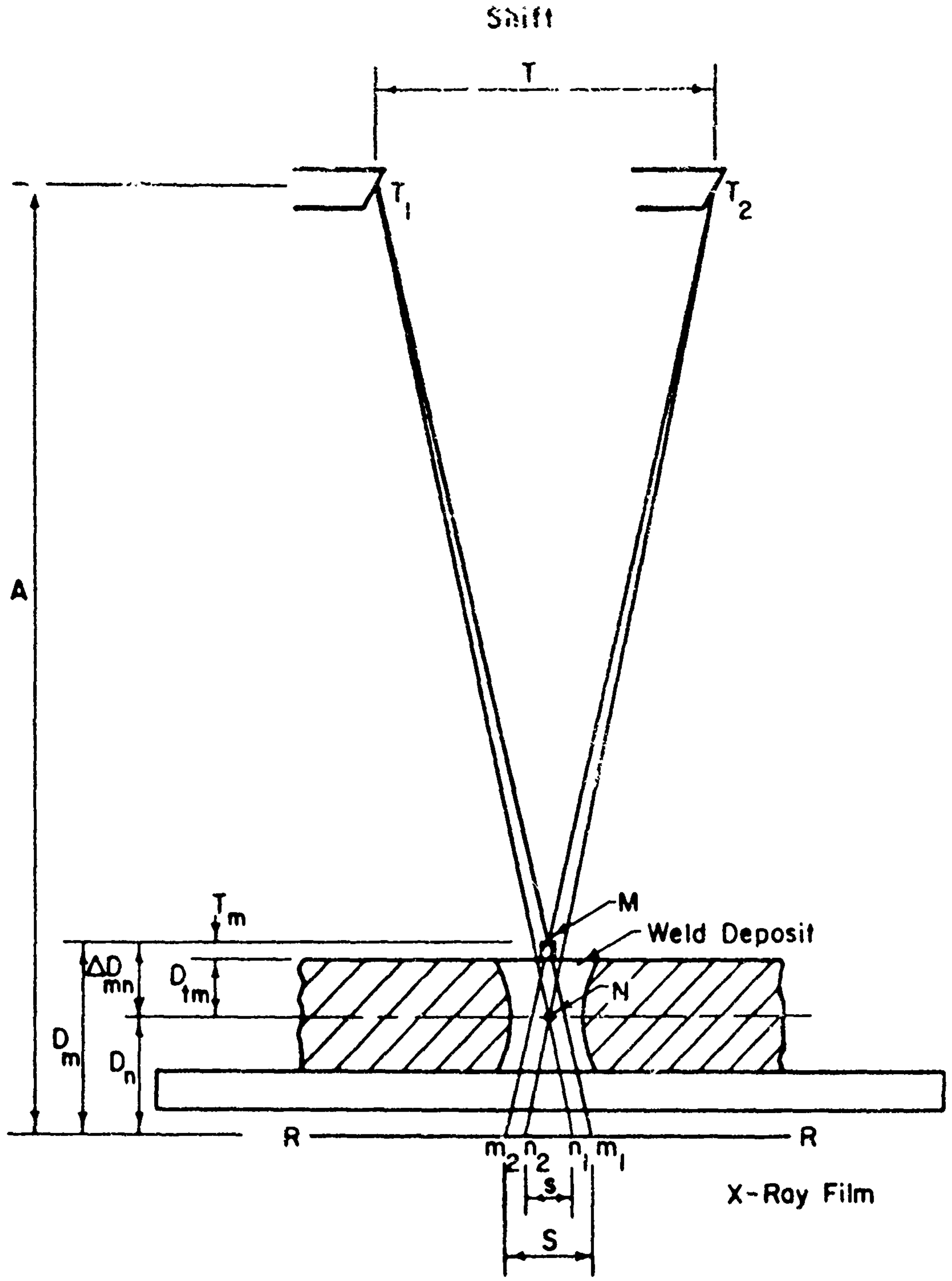


Fig. 1. Geometry of the Stereoradiographic Technique: The Shift between Exposures is Shown as a Translation of the X-ray Source for Simplicity.

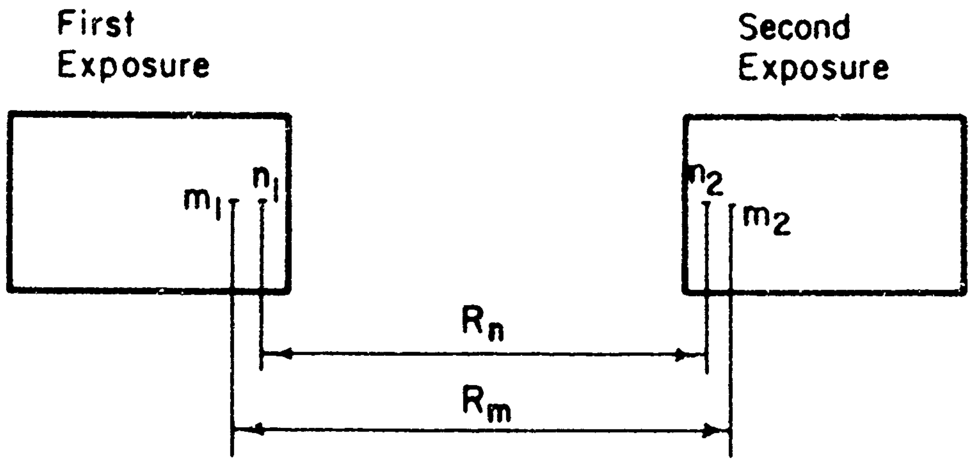


Fig. 2. Schematic Arrangement of Stereo-Pair Resulting from the Experiment Shown in Fig. 1. The Important Value is the Parallax Difference, $\Delta S_{mn} = |R_m - R_n|$.

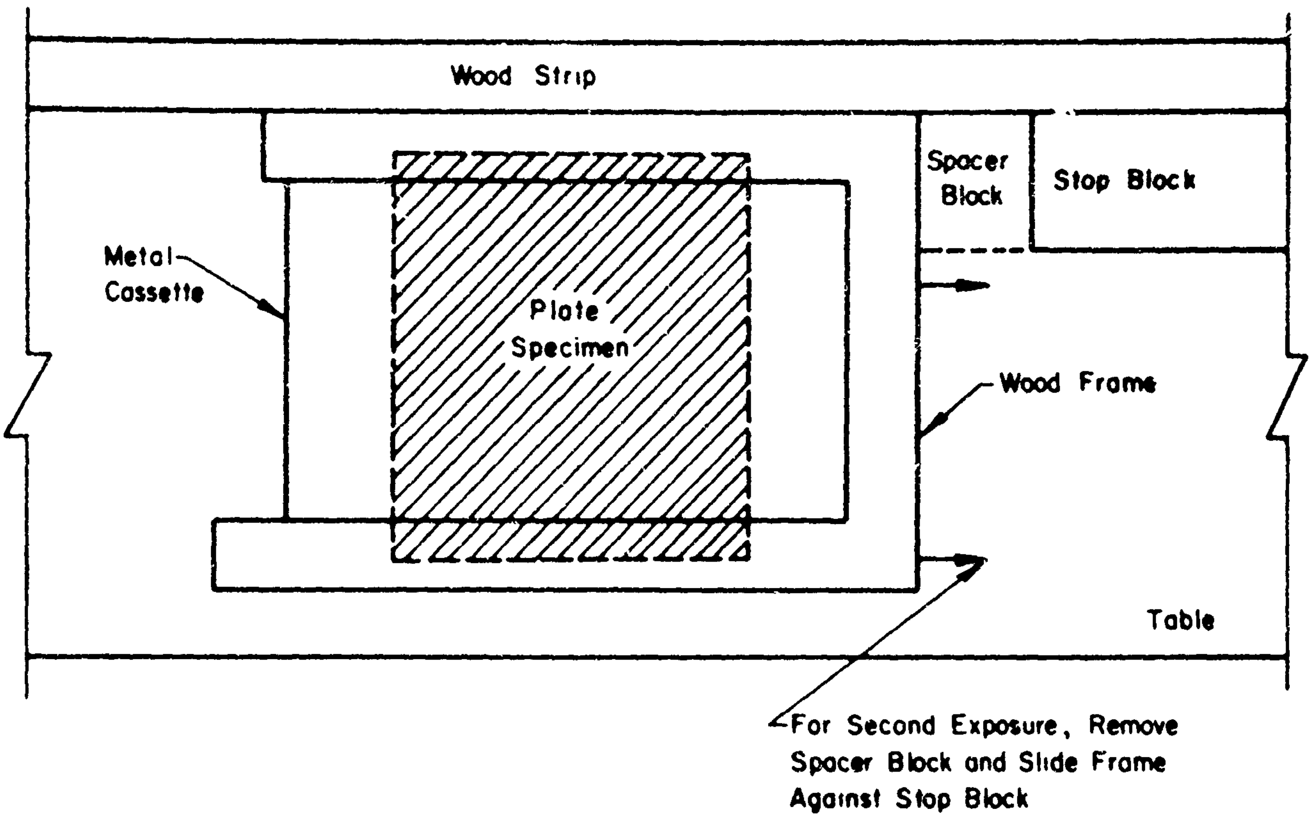


Fig. 3. Schematic Plan View of Guides and Spacers Used for Accurately Performing the Specimen Shift.

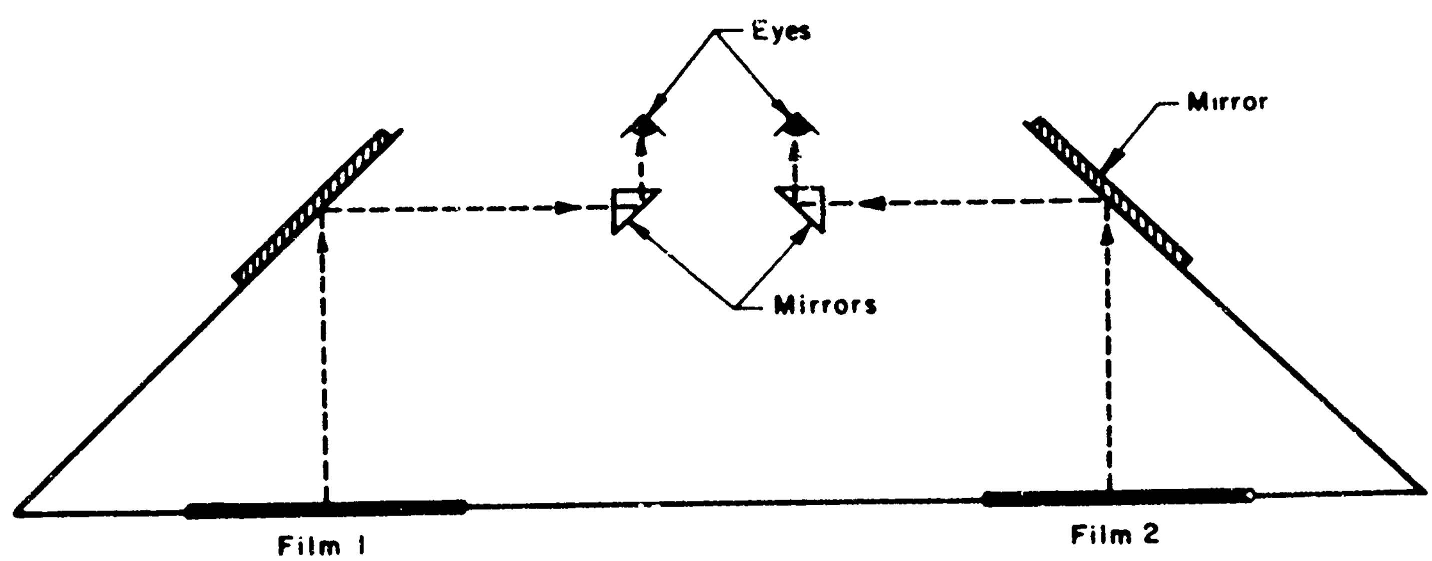


Fig. 4. Principle of the Mirror Stereoscope.

PAPER #11

ABSTRACT

USE OF CLOSED CIRCUIT TELEVISION IN GUN TUBE INSPECTION

Successful application of Closed Circuit Television (CCTV) for visual inspection of gun bore surfaces for defects has been achieved by Watervliet Arsenal. The system was designed to replace the conventional optical Borescope. The use of the CCTV system provides for group viewing and evaluation by technical teams. It simplifies the task by reducing inspection time and eliminates possible human errors due to eye fatigue.

The system features a high resolution vidicon camera housed in a special cradle with an adapter to receive viewing heads. The camera also has built-in jacks to accommodate the lighting system in the viewing heads. The camera and the viewing heads are designed for insertion into the bore of cannon tubes for examining the bore surfaces. Different viewing heads have been designed to provide for down bore and right angle viewing.

A Borescope can be used in conjunction with the CCTV system to inspect the surfaces of bores too small to accept insertion of the TV camera. The size of a bore that can be inspected is limited only by the size of the Borescope.

The CCTV inspection system developed at Watervliet Arsenal is being applied for acceptance inspection in the production area and for engineering evaluation of test fired development cannon tubes.

J. J. Fiscella
Chief, Metrology Design Branch
Quality Assurance Division
Watervliet Arsenal
Watervliet, New York 12189

PAPER NO. 11

USE OF CLOSED CIRCUIT TELEVISION IN GUN TUBE INSPECTION

J. J. FISCELLA, WATERVLIET ARSENAL

The visual inspection of the bore surfaces in a gun tube, to evaluate the surface quality and to uncover material defects such as cracks, voids, inclusions and damage due to firing, is accomplished conventionally through the use of a Borescope. This is one of the more critical inspections conducted on a gun tube and it is conducted during engineering testing - to determine suitability of materials, in the production area - to determine the acceptability of gun tubes and in the field - to determine the serviceability of tubes.

The Borescope (See figure 1) is an optical instrument composed of:

- An Eyepiece Assembly
- An Adapter Tube Assembly
- One or more Extension Tube Assemblies
- An Objective Tube Assembly
- An Illuminating Head Assembly
- A Power Supply Assembly

The bore of the weapon as seen through a Borescope is usually not life size. Due to the various size bores to be inspected and the design of the Borescope, the magnification of the viewed area varies.

Bore searching (see figure 2) the internal surface of a cannon tube through an optical instrument such as the Borescope with its limited field of view and magnification is a slow tedious job.

In view of the obvious advantages that could be derived through the use of Closed Circuit Television in gun tube inspection, and the disadvantages inherent in the present optical viewing system, an investigation of Closed Circuit Television as a means of visually inspecting cannon bore surfaces, was undertaken by Watervliet Arsenal.

The advantages that could be derived through the successful application of a Closed Circuit Television System have been recognized for some time. Preliminary investigations conducted in earlier years disclosed that the television picture was unsuitable due to poor resolution and definition. However, in view of the advances made in the electronic field, re-evaluation was in order. If a TV system could produce a picture suitable for the critical evaluations that must be made relative to the indications uncovered in the bore of a gun tube, obviously these advantages will result:

a. Inspection time would be reduced.
b. Eye fatigue associated with the use of the present optical viewing system (Borescope) would be eliminated.
c. Defect evaluation would be facilitated due to the increased magnification possible with TV.
d. Surface indications could be viewed by more than one person at the same time.

Our investigation of Closed Circuit Television to improve the present method of inspecting cannon bore surfaces, required the evaluation of available systems that could be adapted to suit our purpose. Various systems were studied and based on our findings, specifications were prepared for a high resolution TV system.

A prototype system was manufactured in accordance with our specifications (See figure 3). The prototype system consisted of a high resolution solid state camera with a 14 inch screen monitor, a camera control unit, a 25mm and a 50mm lens, a 90 degree prism head and aluminum extender arms with the necessary connectors. The prototype system produces 1225 scan lines per frame. Commercial broadcast TV produces 525 lines per frame. The 50mm lens provides a magnification of approximately 12 to 1 and the 25mm lens provides a magnification of approximately 6 to 1 when used with the 90 degree prism head.

The field of view, of course, is dependent on the size of the lens used with the camera. The field of view obtained with the 50mm lens is one half that obtained with the 25mm lens.

The Closed Circuit Television system equipment set-up is somewhat similar to that of the present optical system (See figure 4). With the TV system completely assembled, the camera with the illuminating viewing head attached is inserted into the muzzle or breech end of the tube. It is necessary to focus the TV camera lens to suit the bore size of the tubes to be examined. Power remote focusing is available on some systems.

The tests conducted with the prototype Closed Circuit Television system clearly demonstrated that the equipment could be applied successfully in the inspection of gun tubes (See figure 5). The Closed Circuit Television equipment with its compact, lightweight camera unit, when compared with the optical Borescope, offers the advantages of low operating costs, high resolution and greater magnification. It provides a more efficient method for visually inspecting cannon tube bore surfaces by eliminating eye-fatigue which results from bore searching through a Borescope and minimizing disagreements due to the differences in vision between individuals. In using the Closed Circuit Television system there is no loss of illumination when inspecting the longer tubes. With the Borescope there is a loss of illumination as the light must pass through more lenses because of the increased number of extension tubes that must be used when inspecting the longer tubes.

In addition to these advantages, evaluation of a surface indication is facilitated as more than one person can view the indication at the same time, at a much higher magnification. Scanning the bore surfaces for indications is faster with the higher magnification and the elimination of "eyeballing" through an optical instrument. Our test results indicate a scanning rate of seven feet per minute using the

Closed Circuit Television system versus two feet per minute using the Borescope. Smaller inclusions or defects can be detected as a result of the higher magnification and the clarity of the image produced on the TV screen.

The height of the cannon tube from the floor is not restricted as with the Borescope, which requires that the tube be placed at a convenient height for viewing through an optical instrument.

The picture obtained with Closed Circuit Television can be recorded using a commercially available videotape recorder.

Maintenance costs for Closed Circuit Television equipment are reasonably low and personnel with limited training can easily operate and maintain the system.

The TV camera uses a vidicon type of image tube for scene observation. The camera is capable of operating with a variety of vidicon tubes without any additional modification required to the camera.

The lens used and the area to be observed determine the position of the camera. The field of view or perspective can be varied depending upon the selection of the lens.

A number of design considerations for special equipment for use in conjunction with the Closed Circuit Television system to visually scan the bore of cannon tubes were investigated during the development period. The following is a description of the most economical and practical designs to achieve the desired results.

a. The design of the TV camera housing cradle assembly (see figure 6 and 7) features interchangeable teflon supports to accommodate the different bore sizes to be inspected. The function of the cradle assembly is to act as a protective framework for the camera and to maintain the center of the vidicon tube in relation to the center of the teflon supports and the bore being inspected.

b. The design of the adapter assembly (see figure 8) permits detent positioning for ease of proper focusing to different bore diameters and for mounting the 25mm or 50mm lens.

c. The adapter assembly may be equipped with any one of various types of viewing heads, all of which are interchangeable. The viewing heads contain the lamps that illuminate the object under inspection. They also direct the cone of view to various angles as required. The illuminating viewing heads are designed for a wide variety of industrial and military uses.

d. The prism head (see figure 9) bends the cone of view at a right angle to the axis of the camera, thus giving a direct view perpendicular to the camera. This head provides the higher magnification and is generally used for the more critical inspection or to more closely evaluate a suspected area. Figure 10 shows a picture of the bore evacuation valve hole on the 152mm tube as viewed with the prism head.

e. The circumference or panoramic head (see figure 11) is designed for the scanning of tube bores. Because of its length, the design provides for interchangeable teflon supports of various sizes to accommodate the different bore sizes being inspected. It projects the field forward to view the wall at slanting incidence. Thus a 360 degree band several inches in length is seen in the field of view (see figure 12). A centrally located mirror provides a near right angle view for the more critical study of defects. The mirror is adjustable to provide for focusing. Figure 12 shows the monitor televising the bore evacuation valve hole as viewed on the mirror.

f. The bottoming head (see figure 13) with its ring of lamps allows the cone of view to pass through without the interference of a mirror, to produce a view of the bottom of blind holes or cavities. To illustrate a blind hole application, figure 14 shows a picture of the breech end of the tube looking at the front face of the chamber on the 152mm gun.

The Closed Circuit Television camera has been coupled successfully to Borescopes to inspect bores too small for insertion of the camera (see figure 15). Figure 15 shows such a system for inspecting a 20mm gun tube. The image produced by the Borescope is televised and magnified on the monitor screen (see figure 16). The smallest bore size that can be inspected utilizing a TV camera with a Borescope is limited only by the size of the Borescope used. Figure 16 illustrates a system for small arms application. The set up is for inspecting the M16 rifle barrel. Figure 17 shows a view of an area inside a chrome plated M16 barrel obtained with the camera coupled to a small Borescope.

Test results showed that the Closed Circuit Television inspection system transmits a detailed picture of the bore surfaces at a greater magnification than that obtained with a Borescope. The conventional inspection method using just a Borescope, although adequate, causes undue operator fatigue and discomfort and increases the probability of human error in the evaluation of surface defects. Thus, inspection time and costs are higher than desirable. The Closed Circuit Television inspection system virtually eliminates the disadvantages inherent in the use of the optical Borescope and it is presently being used for acceptance inspection in the production area and for engineering evaluation of test fired development cannon tubes.

J. J. Fiscella
Quality Assurance Division
Watervliet Arsenal
Watervliet, New York 12189

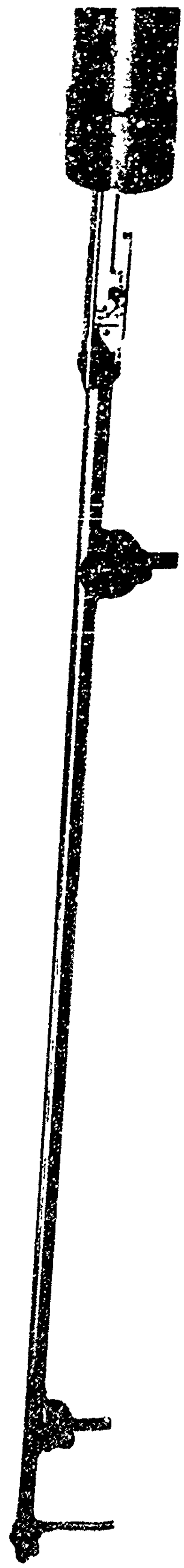


Figure 1

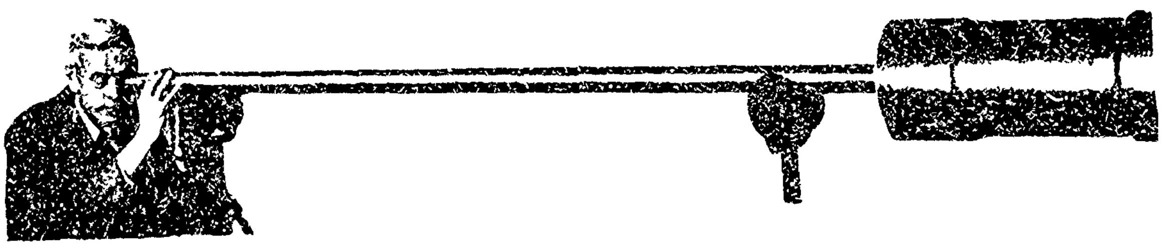


FIGURE 2.

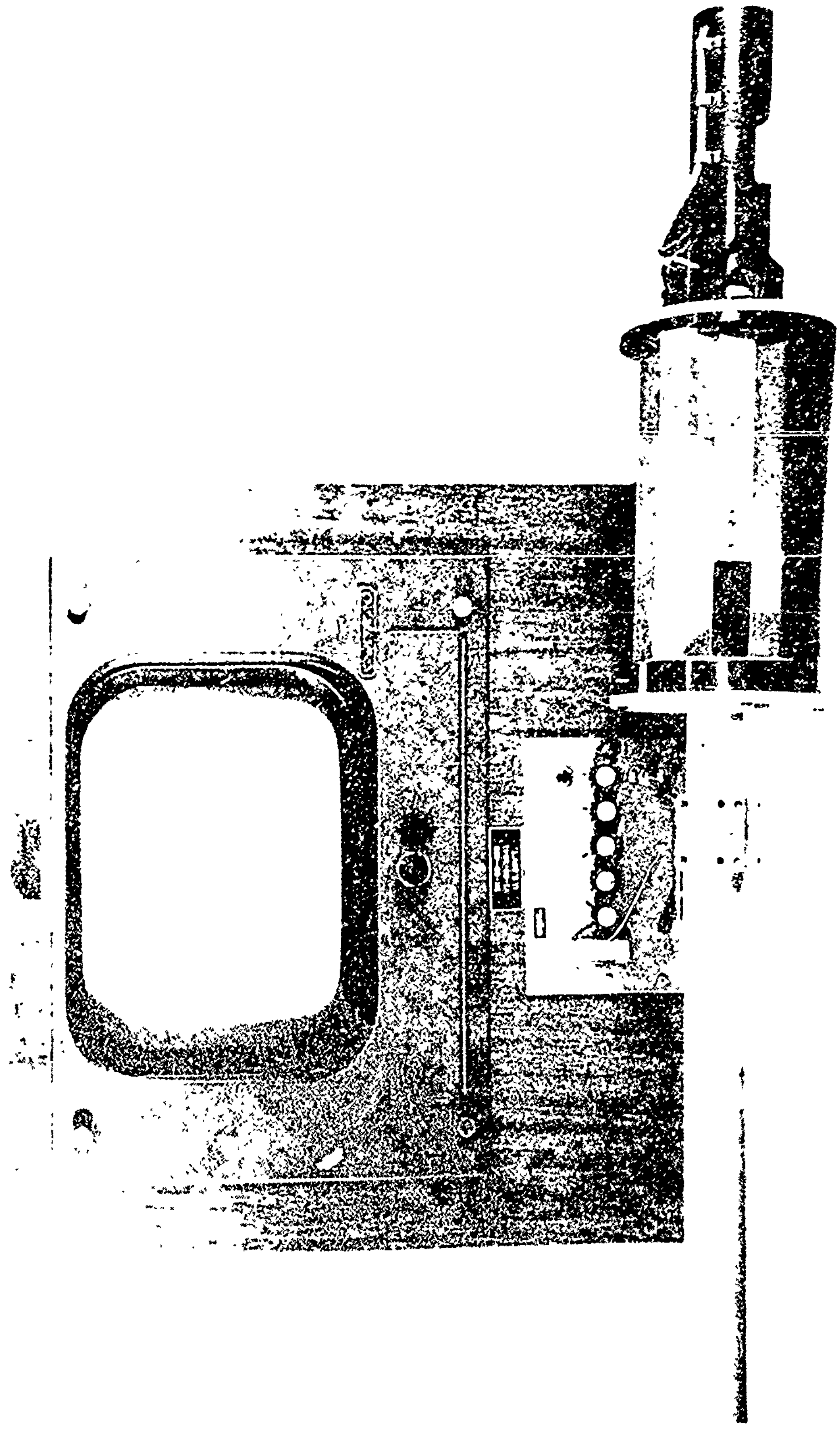


FIGURE 3.

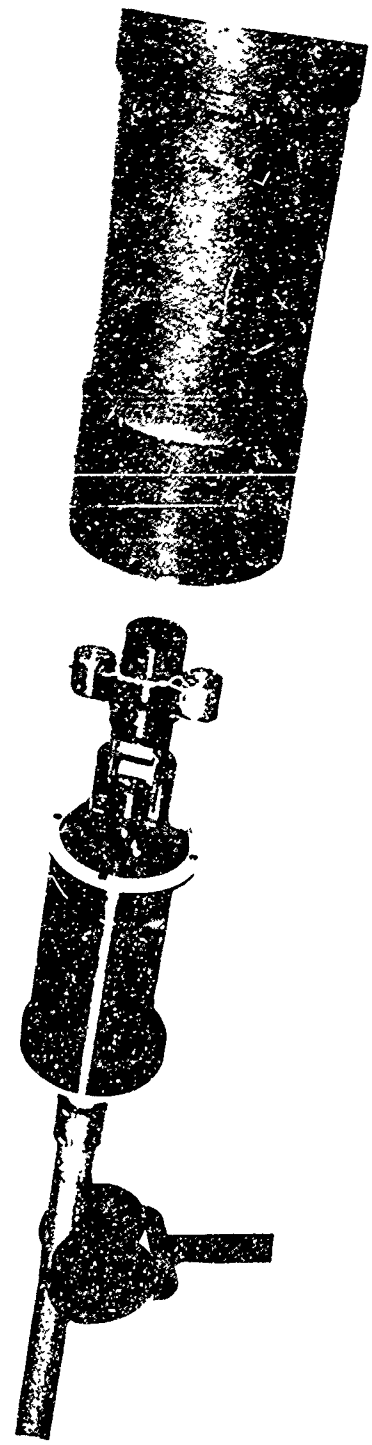


Figure 4

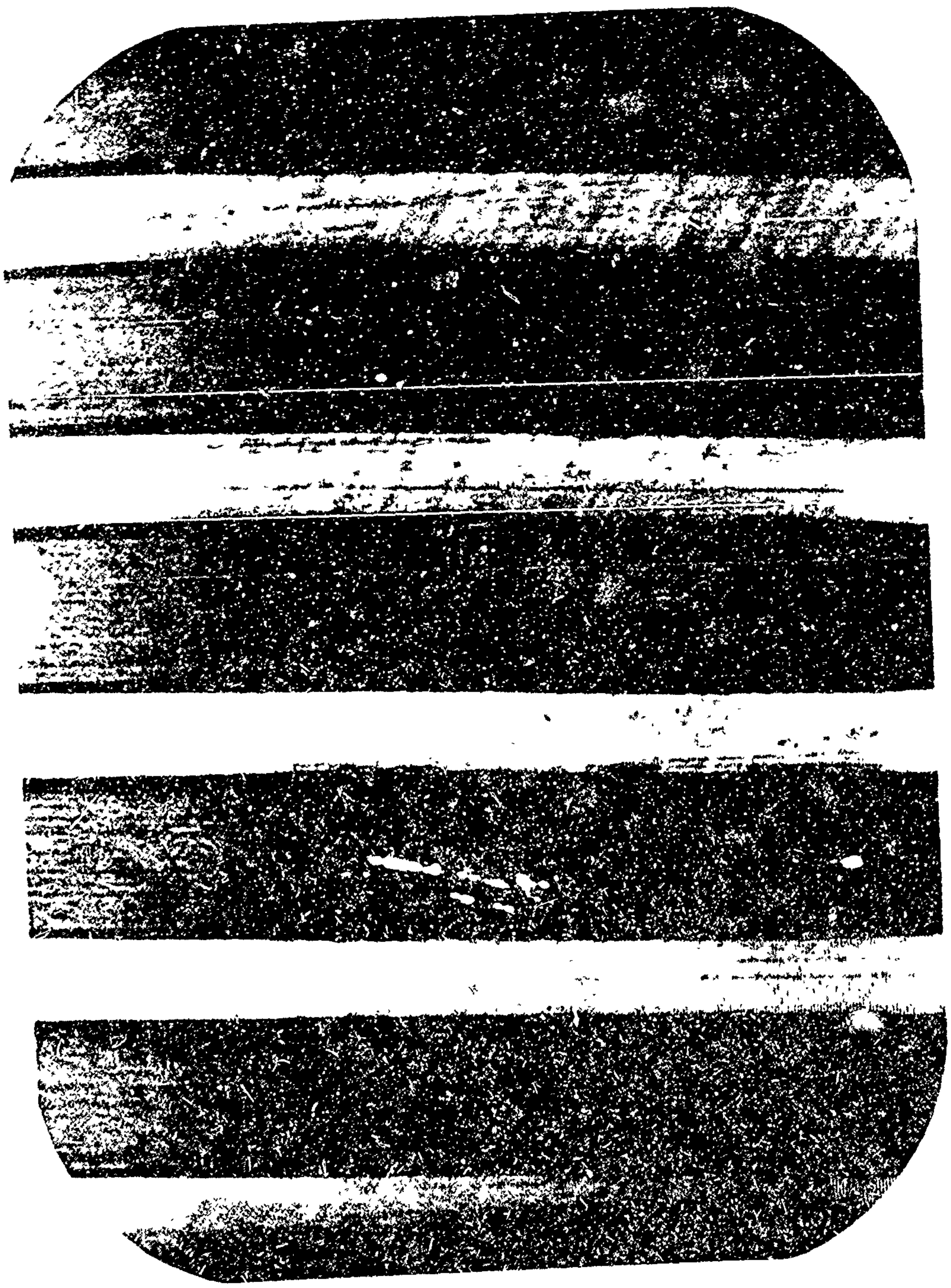
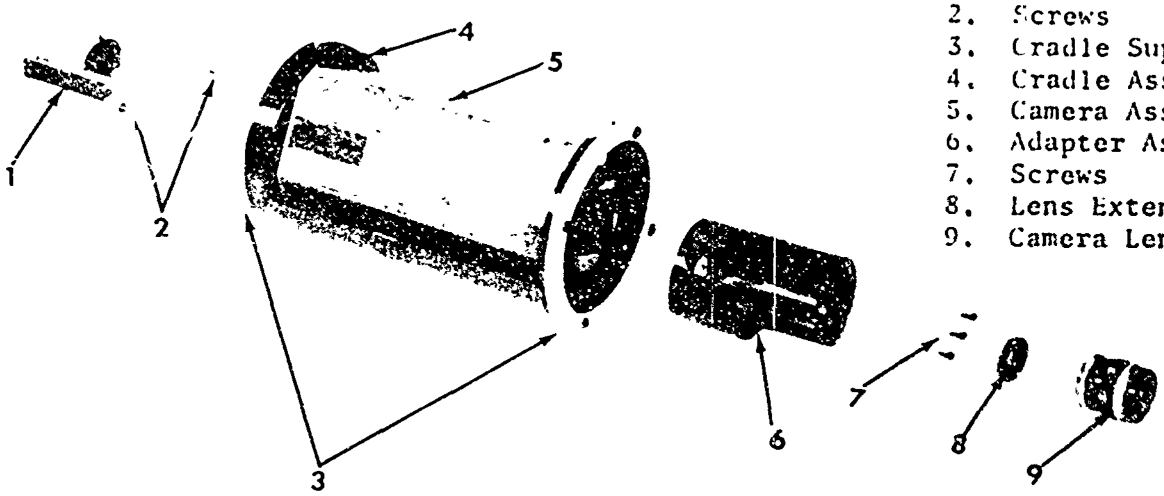


Figure 5



1. Brace
2. Screws
3. Cradle Supports
4. Cradle Assembly
5. Camera Assembly
6. Adapter Assembly
7. Screws
8. Lens Extender
9. Camera Lens

Figure 6

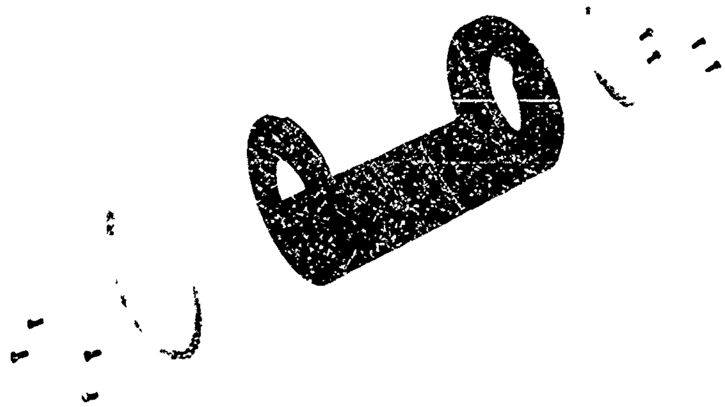


Figure 7

Figure 8

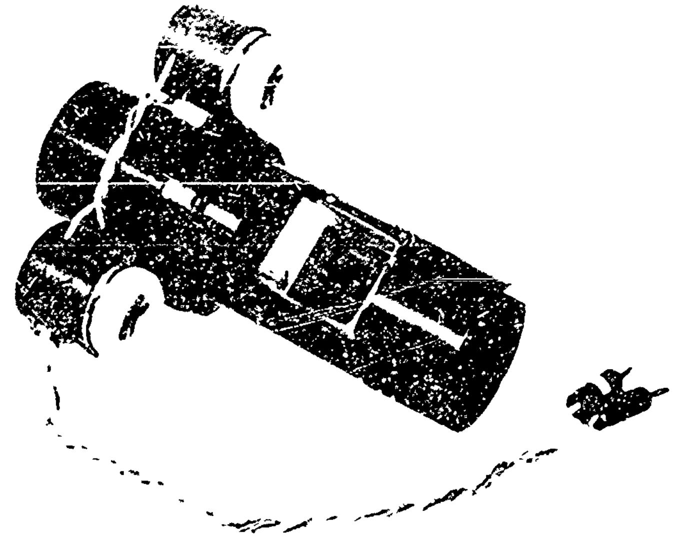


Figure 9

FIGURE 10.

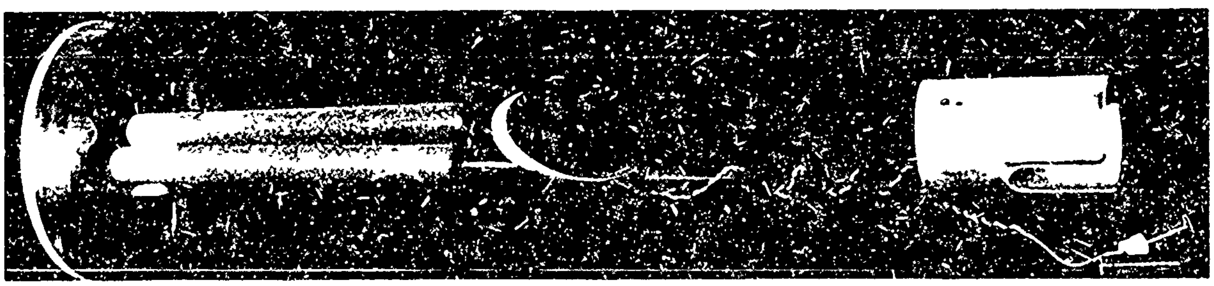


FIGURE 11.

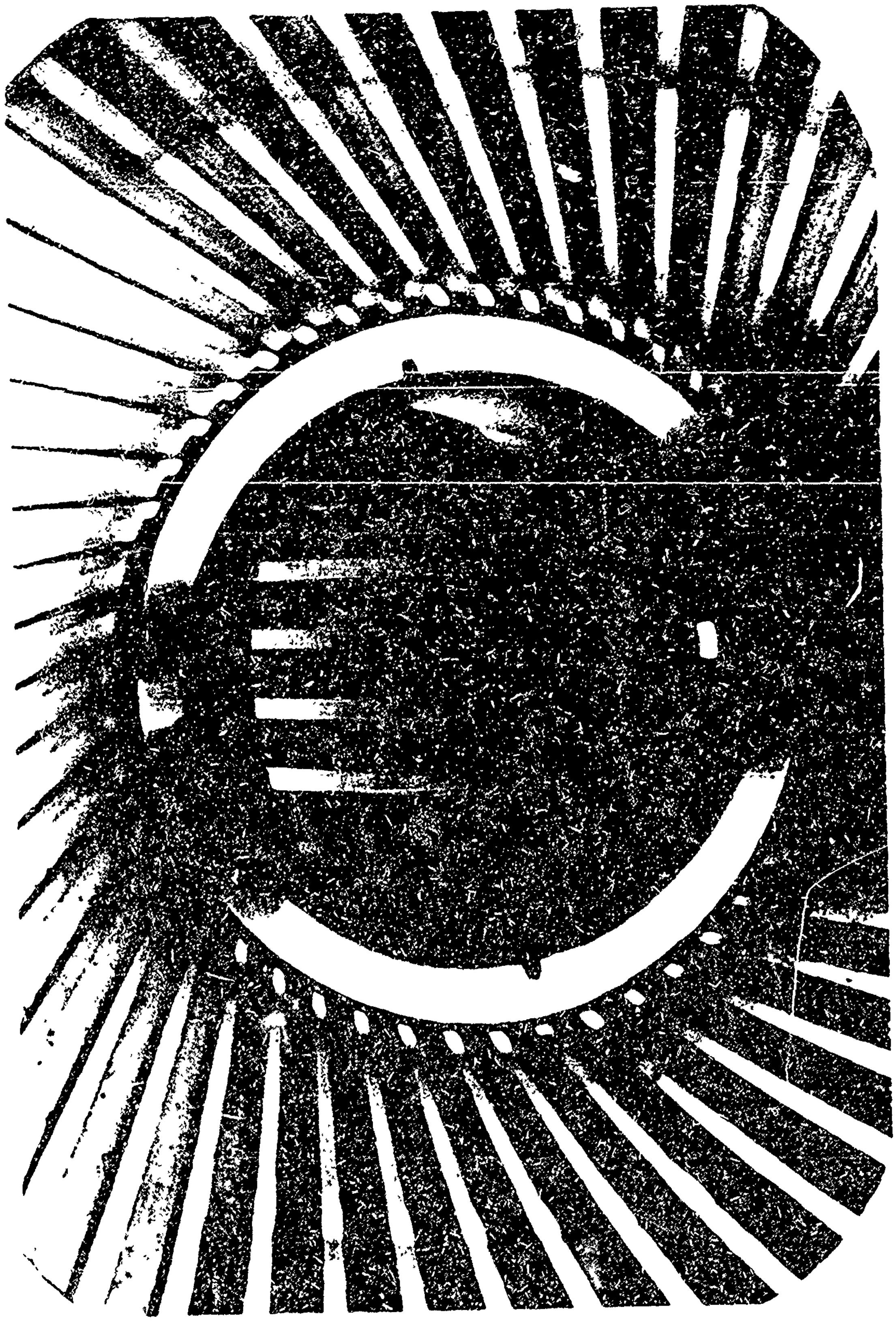


FIGURE 12.

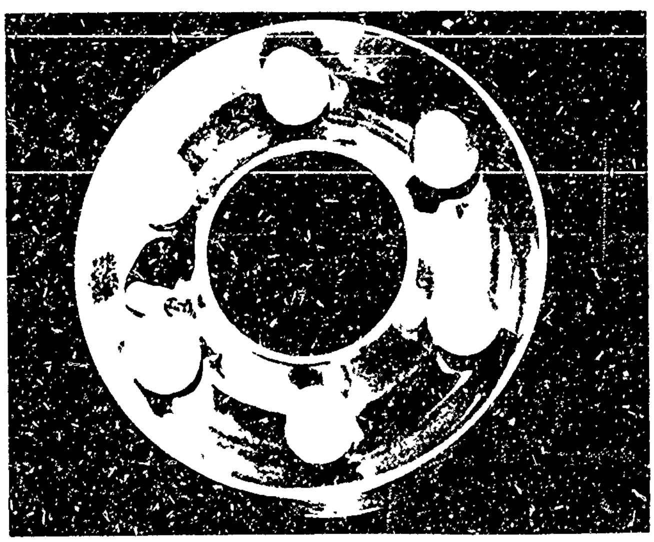
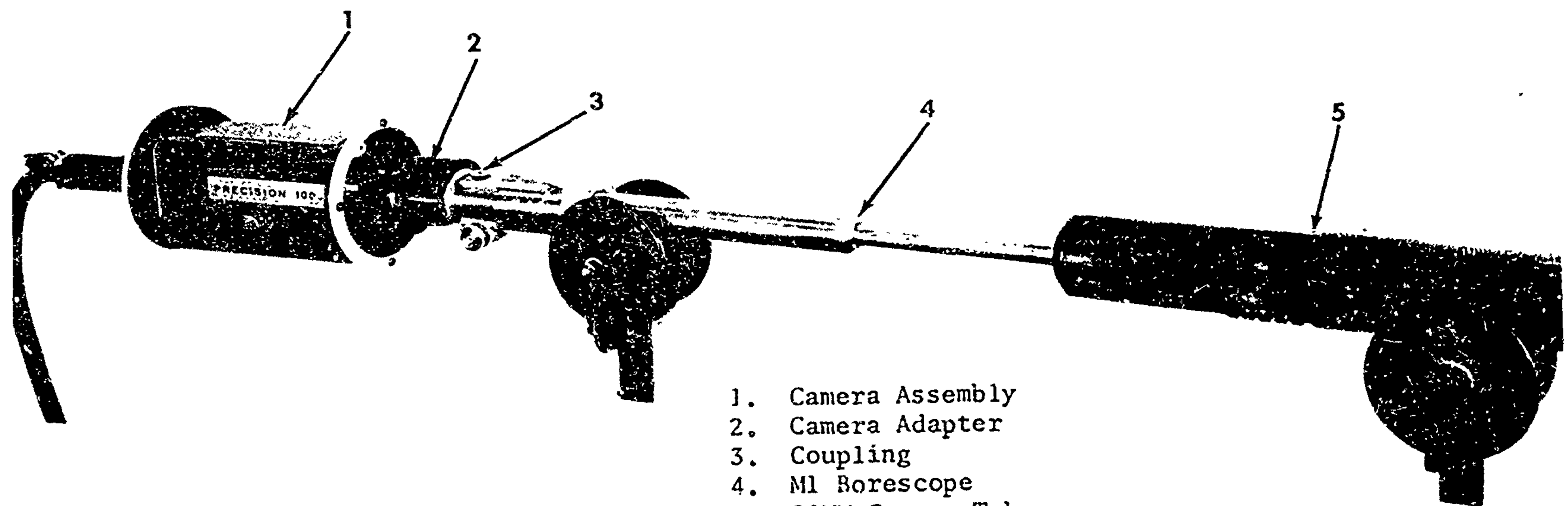


FIGURE 13.

Figure 14



1. Camera Assembly
2. Camera Adapter
3. Coupling
4. M1 Borescope
5. 20MM Cannon Tube

Figure 15

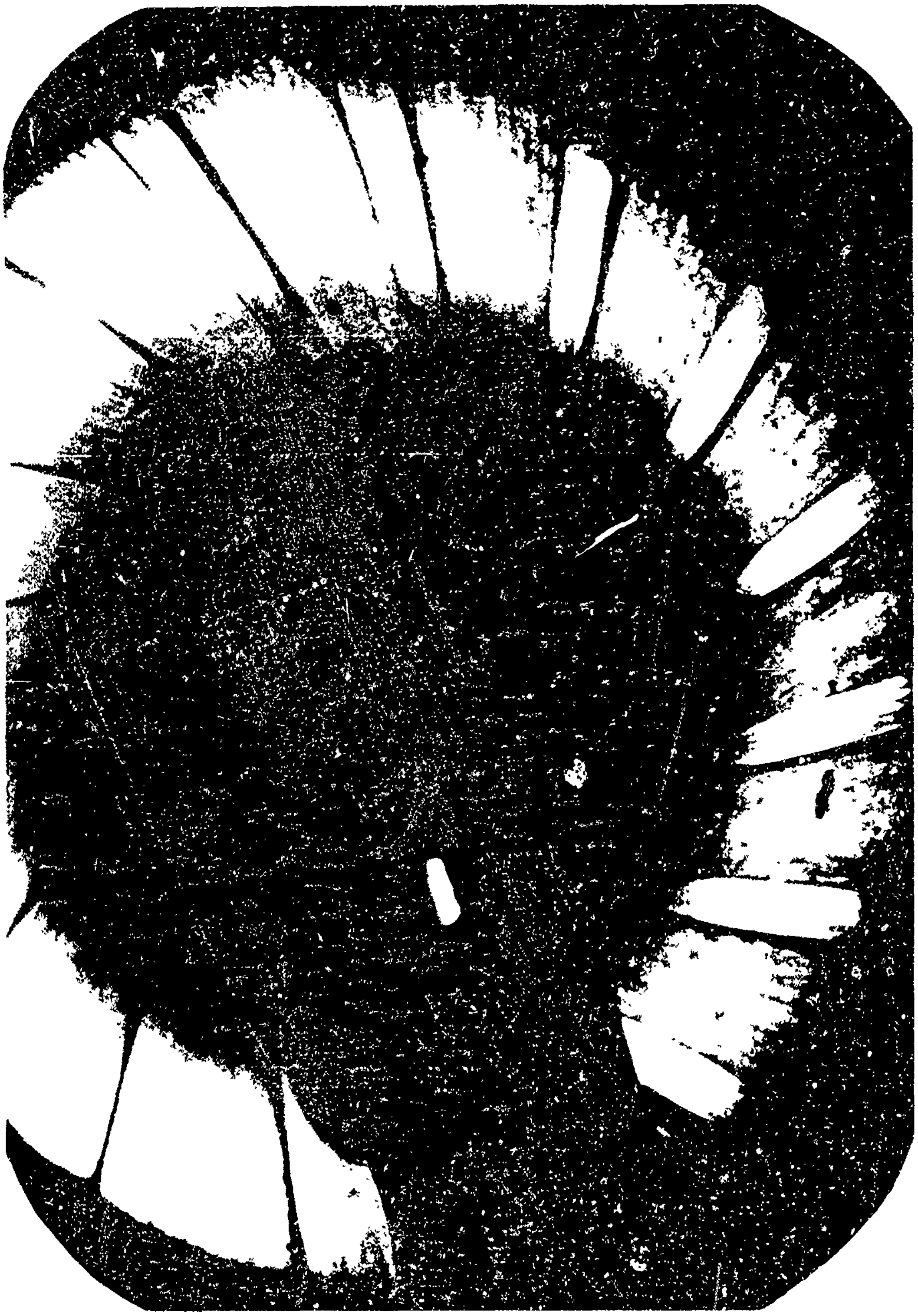


Figure 16

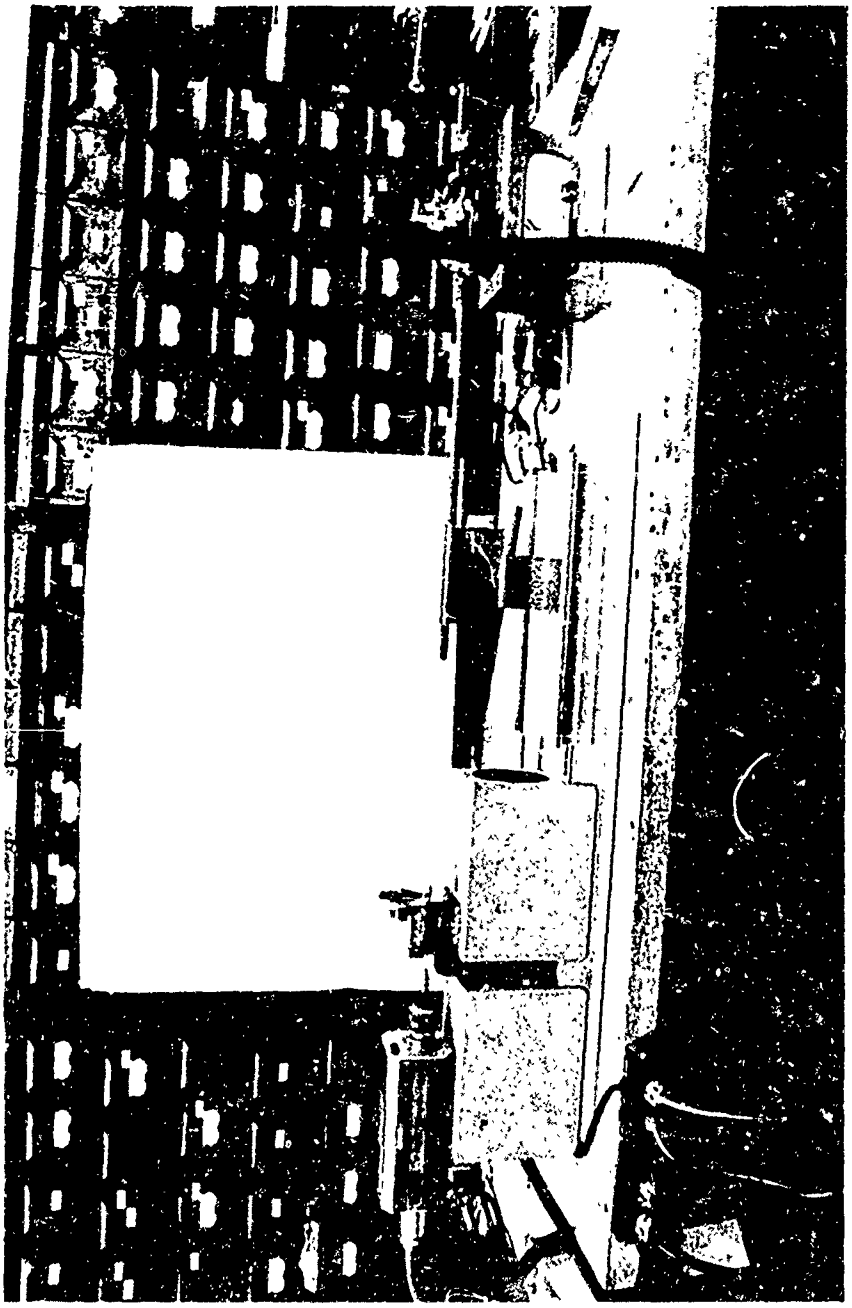


Figure 17

Figure 18

PAPER # 12

ABSTRACT

A LOW COST EDDY CURRENT CRACK DETECTOR

At Watervliet Arsenal an eddy current crack detector has been developed which uses less than $50 worth of parts and which can locate cracks in steel at scanning speeds of 15 to 600 surface feet per minute. In comparison, a commercial eddy current crack detector, selling for $5200, has scanning speeds of 100 to 300 surface feet per minute. Each machine lights one lamp when the transducer traverses a surface defect 0.010 inch deep or more, and another lamp if the defect is at least 0.025 inch deep. No light indicates that no surface crack is as deep as 0.010 inch. One light indicates that no surface crack is as deep as 0.025 inch. Two lights locate where there are cracks which may be more than 0.025 inch deep. Other depths may be selected by simple adjustments. These lamps are controlled by relays in both machines so that, by suitable adaptation, bells can be rung or different colored paint can be sprayed on the defects. Calibration on saw cuts in similar metal must be made at the scanning speed.

The paper presents the schematic diagram of the low cost machine, some theory of operation and a few typical waveshapes to aid in troubleshooting. The device will be demonstrated.

Herbert Frankel
Watervliet Arsenal
Watervliet, New York 12189

PAPER NO. 12

A LOW COST EDDY CURRENT CRACK DETECTOR

HERBERT FRANKEL, WATERVLIET ARSENAL

PROBLEM STATEMENT

Eddy current devices can locate surface cracks in metal faster than ultrasonics, magnetic particle or any other method. Commercial eddy current crack detectors scan at speeds up to 300 feet per minute, but, exclusive of fixturing, one costs $5200. This price is a deterent to widespread adoption of this inspection method. It would be desirable to develop an eddy current crack detector which would cost less than $500. It would be advantageous also if the scanning speed were increased in order to reduce the inspection time.

THEORY

If a coil of wire in free space is connected to a constant voltage sinusoidal oscillator, a current of I. amperes would flow. This current would not noticeably change if the coil were in air provided that there is no metal nearby. Magnetic flux flows through the coil caused by a magnetomotive force which is produced by ampere-turns, the product of the current and the number of turns in the coil. Assume that a flat aluminum plate is put beneath the coil as in figure 1, the changing flux in the coil causes eddy currents to be set up in the plate. Notice that the eddy currents flow opposite in direction from the original current and they are of the same frequency. When viewed from the top, the coil current flows clockwise, while the eddy currents flow counterclockwise.

The magnetomotive force directed upward, H_E, produced by the eddy current amperes, tends to cancel the H_1 which is directed downward. This tends to reduce the magnetic flux through the coil. However, the flux is determined by the R.M.S. value of the applied voltage, the frequency and the number of turns. Therefore the flux tends to remain at its original sinusoidal value. To accomplish this, more amperes flow into the coil trying to maintain the net ampere-turns the same.

Changing the plate from aluminum to 302 stainless steel increases the resistivity by a factor of 25 consequently reducing the eddy current and reducing I. The 302 stainless steel is nonmagnetic; it is impossible to make a permanent magnet of this material. Suppose the material of the plate were changed to a magnetic steel which is a good conductor of flux. It would now take fewer ampere-turns to send the same flux through the coil and I would be further reduced. In addition, the eddy currents would tend to flow along the surface of the plate instead of penetrating. The depth of penetration in hardnened magnetic steel is only about 1/10 of the depth in nonmagnetic stainless steel for the same frequency. Increasing the frequency decreases the depth of penetration.

If there is a crack or void which reaches the surface, some of the eddy currents cannot flow in the previous path and must go around or under the flaw. In either case, the path is longer or more difficult, the eddy currents are reduced, and consequently the coil current is reduced. This is the basis for all eddy current crack detectors.

APPROACH TO THE PROBLEM

The Magnatest S.D. 400 is a commercial eddy current crack detector which has two defect lamps. One lamp lights when the transducer traverses a shallow crack and both lamps light for a deeper crack. This desirable presentation was also used in the circuit of figure 2A which was developed by the author. In that circuit all components to the left of the 1N34 diode comprise an oscillator.

In figure 2A, L1 is the transducer which has a sudden reduction in current when traversing a crack. The tunable coil, L2, tries to maintain a constant current through itself. Therefore, the current entering the base of T1 increases. This flow of current was verified by looking at the increase in voltage across a 30 ohm resistor temporarily inserted in series with the base. As with all transistors in this configuration, an increase in base current causes an increase in collector current. Since L2 resists sudden changes in current through itself, there is a sudden increase in current through the diode in the direction of the arrow.

There may be a question as to why the current in L2 resists sudden change while the current in L1 changes rapidly while traversing a crack. It should be realized that the net magnetic flux through a coil cannot change in zero time since this flux represents stored energy. The current through coil L1 suddenly changes because the eddy current suddenly changed and the net flux must be instantaneously maintained. The magnetic flux through L2 cannot change suddenly either. Since this flux is caused by only one current, that current cannot change suddenly. The momentary increase in current to the left through the 1N34 diode comes out of the base of T2. Accordingly T2 is a PNP type transistor. The capacitor, in series with the base, will stop a steady current but not a momentary one.

The voltage at the base of transistor 1, as seen in figure 3, has a disturbance when L1 traverses a saw cut. Figure 4 shows that the voltage at the base of T1 really is an oscillation. That picture shows that the time for one complete cycle is 6.4 microseconds corresponding to a frequency of 156,000 hertz. Adjustment of L2 can vary this frequency from 140 to 167 kilohertz.

The voltage to the right of the diode is represented in figure 5.

It shows the envelope of the oscillations sharply distorted downward when L1 traverses a saw cut. Figure 6 was taken under the same conditions as figure 5 except that the horizontal scale is expanded to show the individual waves. Both these pictures were taken from the face of a Tektronix RM 564 oscilloscope adjusted for high bandwidth, accounting for the principal difference between figures 4 and 6. Figures 3 and 5 not only reveal a difference in the magnitude of the response caused by a flaw, but also show the typical 180° phase shift of one stage of amplification.

Transistors 2 and 3 remove most of the oscillations and amplify the remaining signals. Transistor 4 is connected as an emitter follower so that the output can be used to supply drive power to a pen recorder. Since this stage has a gain of slightly less than one, it can be omitted if the recorder has a sufficiently high input impedance and the relays are not required. In fact, the rest of the circuit diagram can be omitted if only a recording of flaws is required.

The output oscillogram is shown in figure 7. The short pulses represent a 0.020 inch deep saw cut and the higher pulses represent a 0.040 inch deep saw cut. Both cuts were made by a 0.1 inch wide circular saw. The pulses can be amplified sufficiently to drive a pen recorder but the deflections would be small. It would be better to stretch the pulse so that the pen had more time to move. Also, there would be enough time to actuate a relay which, in turn, could be used to light a lamp, sound a horn or push a button on top of a spray paint can in order to mark the flaw.

To increase the duration of the pulse, a monostable multivibrator circuit is used. In figure 2A there are two of these "one-shot" multivibrators, one consisting of T10, T11 and the associated components. Normally T10 is not conducting except for a very small leakage current. Therefore, its collector is near +13.5 volts since there is very little voltage across the collector resistor. Transistor 11 is conducting, therefore, its collector is near ground potential. The multivibrator capacitor charges, so that its left side is positive through the T10 collector resistor and the base-to-emitter of T11. The positive voltage pulses of figure 7 turn on T10 which drops the voltage on the left side of the multivibrator capacitor. Momentarily the right side of this capacitor drops, turning off T11. The capacitor voltage gradually changes, finally allowing T11 to conduct again, shutting off T10 once more. While T11 conducts, its collector is near ground potential and T9 conducts, thus energizing the relay L4. This condition continues until T11 shuts off, when the relay becomes de-energized. Figure 8 shows the voltage at the base of T9.

Drawn above this circuit is another monostable multivibrator which is identical except for an extra stage of amplification and a variable resistor inserted between the emitter of T6 and ground. When current flows there is a voltage across this resistor and the

emitter is raised above ground. This means there will have to be a larger signal in order to flip the multivibrator and close the relay. Note that a small signal might turn on T5 but unless T6 also turns on there would not be enought time to actuate the relay.

The low cost crack detector is shown in figure 8. It is 4 inches by 5 inches by 6 inches and is battery operated. The Magnatest SD 400 has a volume more than 27 times as great. Both machines are designed to operate with a single transducer. At Watervliet Arsenal their use is primarily for O.D. and I.D. inspection of gun tubes. To contrast, there are eddy current devices for the O.D. inspection of thin tubes and rods which pass through encircling coils, but these require uniform diameter of the material.

The O.D. inspection of gun tubes has been accomplished by allowing the transducer to ride on top of the tube during finish turning. It takes only one more minute after machining is finished to complete the inspection. This requires that the traverse mechanism on the lathe remain engaged until the eddy current transducer completes its travel.

The I.D. inspection of gun tubes occurs after finish reaming. The transducer is fastened to the reaming head and sent through the tube while the lathe speed is increased. The transducer inspection path is a helix with a 1/8 inch lead. A 14 foot long gun tube can be inspected in 8 minutes by the lathe operator. Borescope or magnetic particle inspection methods require skilled operators, more inspection time and crane time.

Herbert Frankel
Watervliet Arsenal
Watervliet, New York 12189

SUMMARY

DISADVANTAGES OF AN EDDY CURRENT CRACK DETECTOR

1. Inspection is limited to devices of simple geometry.

2. Inspection is limited to cracks which come to the surface or very near the surface.

3. Inspection is limited to materials which conduct electricity readily.

4. It is less sensitive to cracks in the direction of scanning.

ADVANTAGES OF AN EDDY CURRENT CRACK DETECTOR

1. It can find cracks faster than any other device.

2. It can be automated easily.

3. Since contact with the inspected material is not required, maintenance is minimal.

4. It can be used by unskilled operators.

5. It is not subject to operator interpretation, fatigue or distraction.

6. In conjunction with a pen recorder, it produces permanent inspection records.

7. Although the depth of crack is not proportional to the pen excursion, a deflection which is less than the deflection on a calibrating saw cut assures that the crack depth is less than the depth of the saw cut.

8. The length of the crack at right angles to the direction of the scan is proportional to the number of pen deflections.

ADDITIONAL ADVANTAGES OF THE NEW CRACK DETECTOR

1. It uses less than $50 worth of parts.

2. It scans at a much wider span of speeds than any other crack detector.

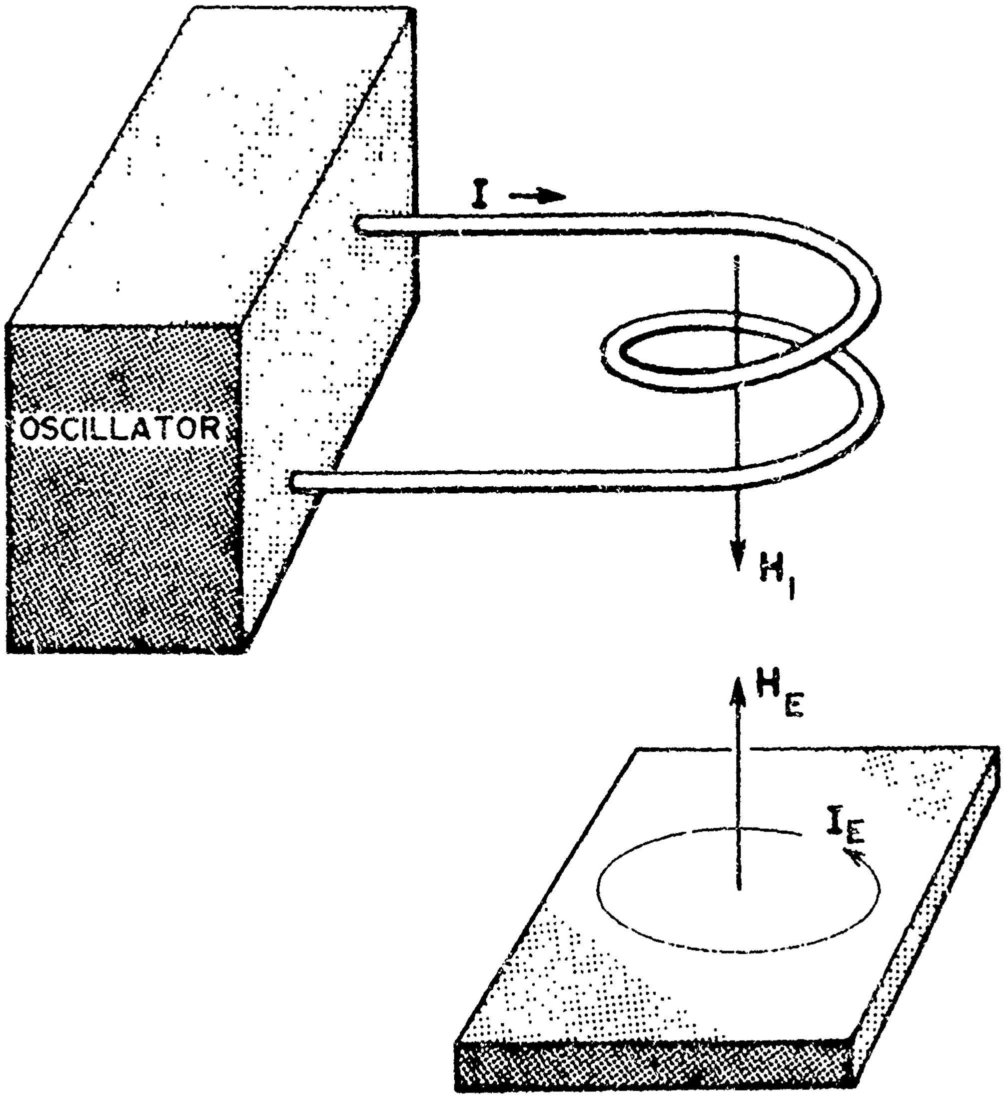


Fig. 1 Eddy Currents Induced in a Flat Plate

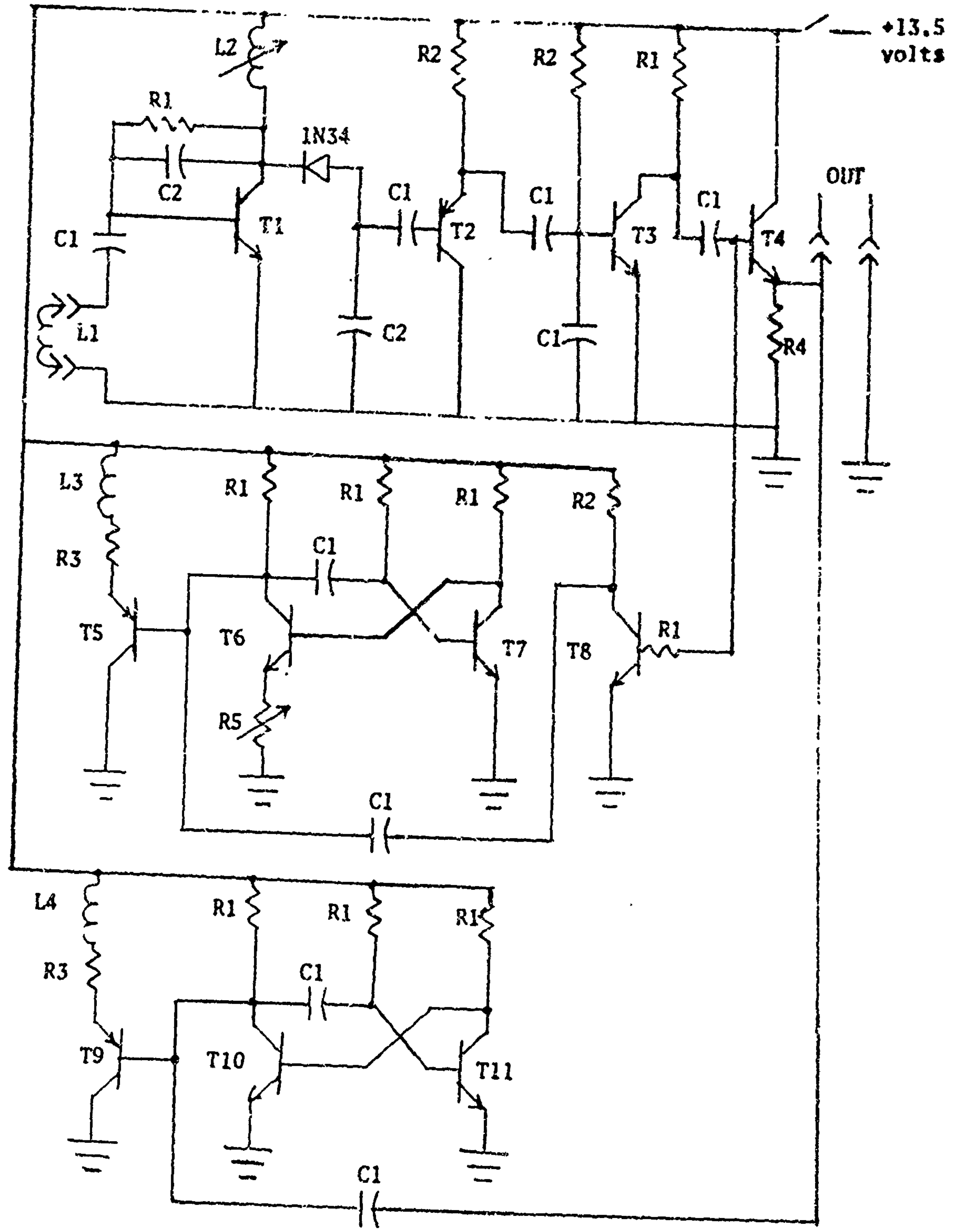


Fig. 2A. Schematic Diagram for Eddy Current Crack Detector

PART	VALUE	NUMBER REQUIRED
R1	100K Ω	11
R2	1 Meg Ω	4
R3	470 Ω	2
R4	3.3K Ω	1
R5	50 KΩ Potentiometer with Knob	1
C1	0.22 μf	9
C2	330 pf	2
L1	200 Turns #39 wire on 1/16" diameter ferrite rod	1
L2	Cambion 1507-5 Coil	1
L3, L4	Relays Sigma 4F 1000 S-SIL	2
IN34	Diode	1
T2, T5, T9	2N711 Transistor	3
T1, T3, etc.	2N697 Transistor	9
BNC	Connectors	2
Lights or Bells		2
Cabinet		1
Plastic Chassis Board		1

All resistors are 1/2 watt but could be 1/4 watt or less if desired, in order to save space.

Fig. 2B. Parts List for Eddy Current Crack Detector

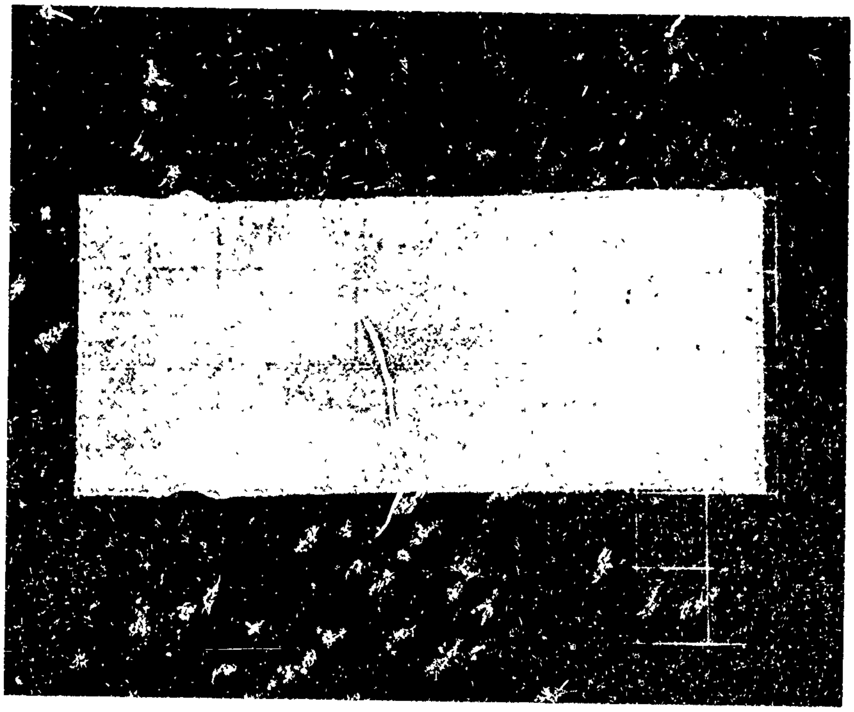


Fig. 3. Base of T1 Showing Disturbance of a Flaw
0.1 Volt/cm. 0.010 sec/cm.

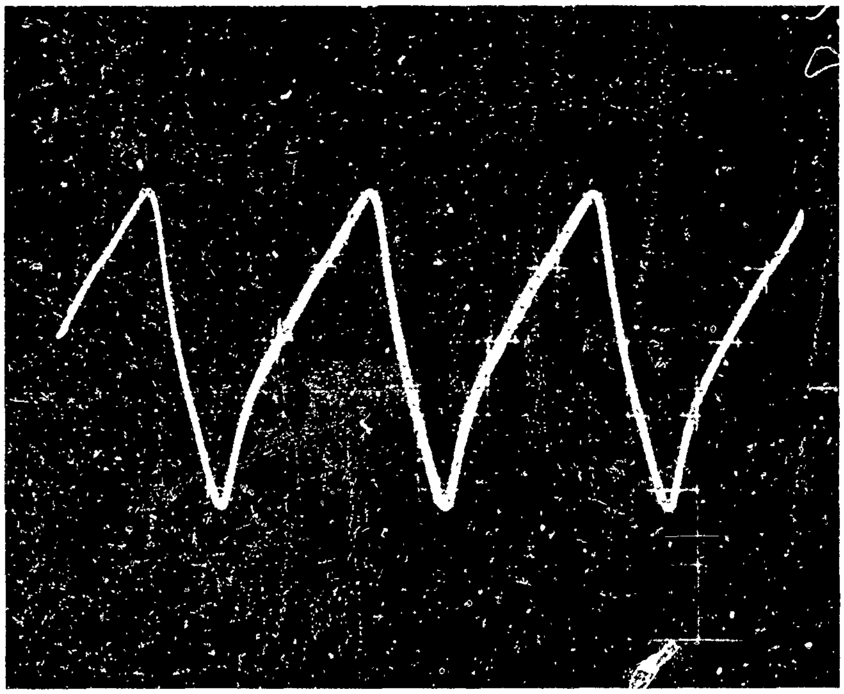


Fig. 4. Base of T1
0.1 Volt/cm. 2 Microseconds/cm.

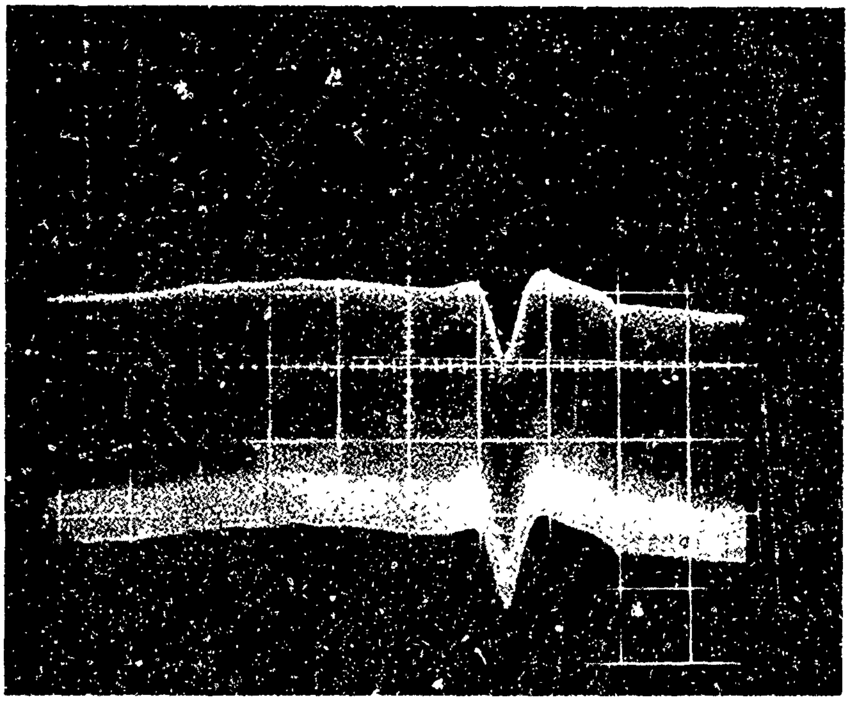


Fig. 5. Anode of Diode Showing Disturbance of a Flaw
0.2 Volt/cm. 0.010 Sec/cm.

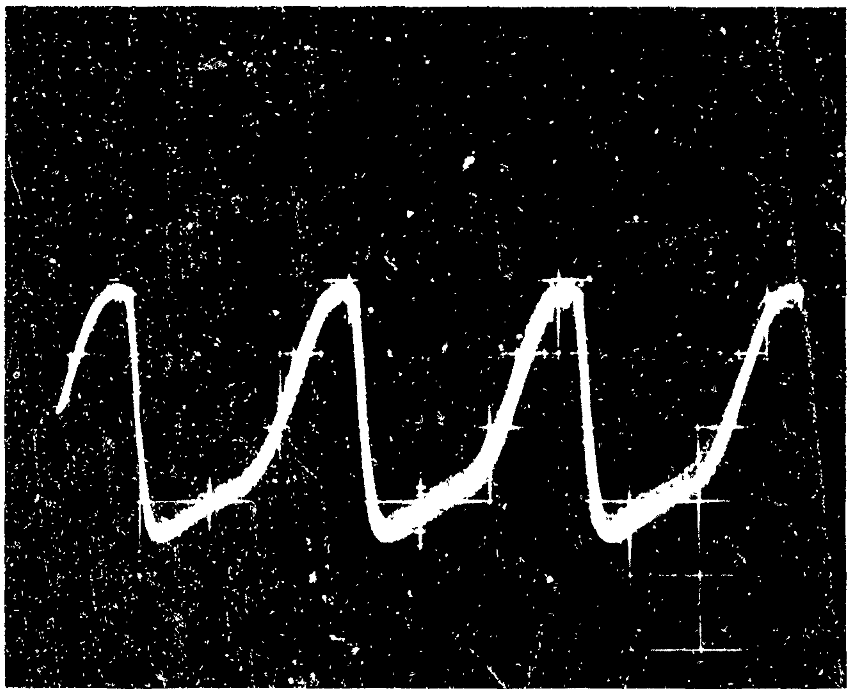


Fig. 6. Anode of Diode
0.2 Volt/cm. 2 Microseconds/cm.

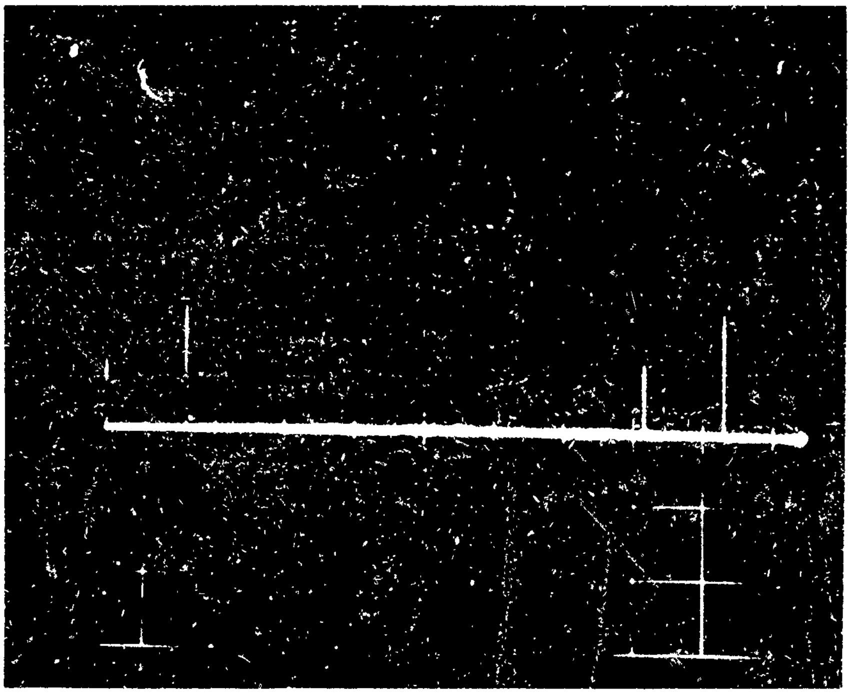


Fig. 7. Emitter of T4 0.020 and 0.040 deep sawcuts
2 Volts/cm. 0.1 sec/cm

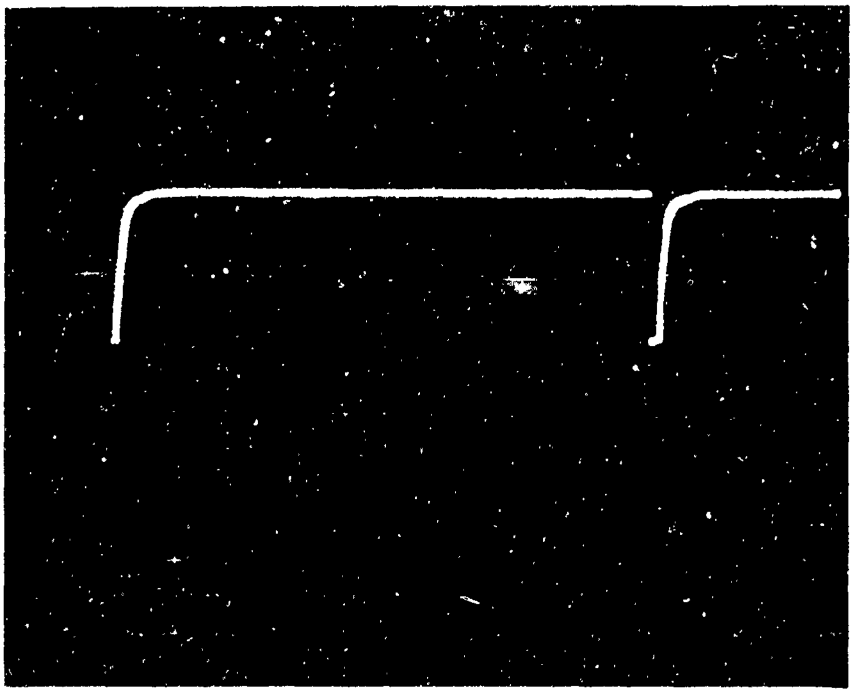


Fig. 8. Base of T4 Showing Disturbance of Flaws
5 Volts/cm. 0.1 Sec/cm.

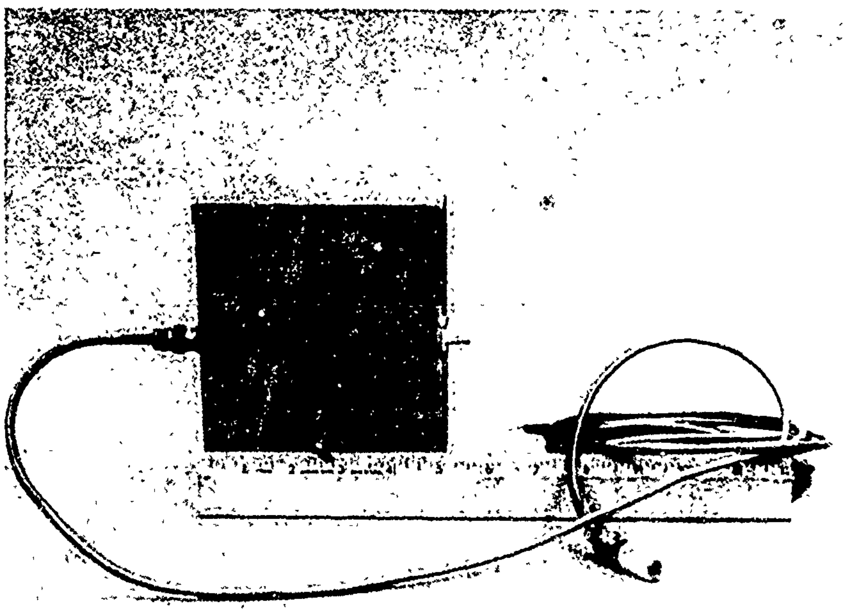


Fig. 9 New Eddy Current Crack Detector with Transducer

PAPER #13

Abstract

A Mixture Monitoring Probe For Pyrotechnic Compositions

Richard J. Frisina, Feltman Research Laboratory, Pyrotechnics Division, Electronics & Photometric R&D Branch, Picatinny Arsenal, Dover, New Jersey

A monitored and controlled procedure for the mixing and blending of pyrotechnic compositions has never been established. A NDT method had to be devised to determine the percentage of composition and homogeneity of mixture because improper and nonuniform compositions result in poor performances and are unsafe due to highly localized reactive regions. Currently the mixtures are processed for a fixed period of time and then random samples are performance tested for acceptance. This is expensive, time-consuming and inaccurate. A new experimental development utilizing fiber optics and reflectance will monitor the actual mixing of the composition and an instantaneous readout of percentage composition and mixture uniformity will be obtained. This system is safe, inexpensive, automatic and remotely operated.

PAPER NO. 13

A MIXTURE MONITORING PROBE FOR PYROTECHNIC COMPOSITIONS

RICHARD J. FRISINA
Picatinny Arsenal
Dover, New Jersey

INTRODUCTION

The determination of when a pyrotechnic composition is completely blended and ready for loading into flares is usually made by human judgment. Quality control procedures are limited to performance testing during or after processing. Automatic methods to monitor these compositions during blending have thus far proven unusable because of the proscription of electrical power in the vicinity of pyrotechnic compositions. The problem is compounded since compositions which are improperly blended are unusable and may be unsafe to handle.

For the first time a nondestructive testing method has been devised to improve the mixing and blending process. This paper describes the progress made thus far in the development of a mixture monitoring probe for a boron-barium chromate delay composition.

PRINCIPLE

The basic principle involved in this technique is that different materials have different reflectivities, and this difference in reflectivity can be used to measure an unknown percentage of these materials. When radiation is incident upon a powdered surface, some of its radiation is directly reflected, some of it is diffusely reflected and the remainder is absorbed by the material. For this application, the radiation was ordinary white light and because no electrical power can be near the composition, light transmitting light pipes or fiber optics as they are commonly called were used to channel the light to and from the pyrotechnic composition.

The fiber optics probe is bifurcated which means that a group of randomly arranged fibers which comprise the probe head are divided into two separate branches. One of these branches transmits the light to the composition and the other branch receives the reflected light and transmits it to a photodetector which produces an electrical signal that is amplified and recorded.

The intensity of the reflected light is dependent upon the composition of the mixture, the spectral characteristics of the incident light and the rest of the optical train. This signal represents the

reflectivity of the composition which is proportional to the percentage of composition. The absolute reflectance of the composition is obtained by calibrating the system with a magnesium carbonate reflectance standard. This is done by adjusting the light source until the digital voltmeter records the known absolute reflectance of the standard. This meter is now calibrated and will register the true reflectance of unknown compositions. For example, with ordinary white light, a white sample such as salt would reflect a greater amount of light than a black sample such as pepper, and a combination of salt and pepper would reflect an amount of light somewhere in between those two extremes, but in a non-linear way as the percentage varies. Also in red light a blue sample would appear black, a red sample would appear red and a white sample would also appear red as only its red component wavelengths are reflected.

Since the color of components of pyrotechnic compositions obviously cannot be changed, the only way to optimize the optical signature is through wavelength selection of the light source that illuminates the composition. The optical signature of the composition is the ratio of the reflectances of its components. To optimize this signature, one component is made to look black with respect to the other. To take another simplified example, if the two components were blue and red, a red source of light would be utilized. This would give the blue sample a zero reflectivity thus making it look black and the red sample would of course look red, and a good optical signature would be achieved.

A spectrophotometer was used to determine if any particular wavelength or wavelength band would provide an advantage over white light in optimizing the optical signature. The spectrophotometer does this by measuring the reflectance of each component versus wavelength and then a comparison is made to see if at any point or band one component has a high reflectivity while the other has a low reflectivity. Once this determination has been made, the remainder of the optical train was designed. For the particular case of a boron-barium chromate delay composition, a white light source was optimum because, as illustrated in Figure 1 and Figure 2, the reflectance of these two components are essentially flat throughout the spectrum.

DESCRIPTION OF THE OPTICAL SYSTEM

The development of this fiber optics probe system was geared specifically to the boron-barium chromate composition. Although the same principle will be applied to other pyrotechnic compositions, the optical system described here applies to that composition specifically. When dealing with other compositions, one or more of the elements of this optical system may have to be changed to optimize its optical signature.

The type of light transmitting fiber optics, either glass, plastic or quartz, the light source, photocell, filters, anti-reflective glass coatings etc., comprise the optical train. Figure 3 shows an

illustration of the apparatus. After the filtered light signal is transmitted, reflected and received through the fiber optics, a photocell senses the magnitude of the reflected signal which, after amplification, is recorded on a chart recorder. The schematic for the amplifier is illustrated in Figure 4.

A standard tungsten-iodine light source with a color temperature of 3000°K was selected as the primary source of light since it has a luminous output of more than 20,000 lumens. The spectral distribution of this light source is illustrated in Figure 5. This light is transmitted down one group of fiber optics having a spectral transmission as shown in Figure 6. These fibers do not transmit radiation beyond the near infrared and transmit about 50% of the visible wavelengths. These glass fibers are readily available and inexpensive.

Since the reflectivity is measured through a glass window in the pyrotechnic blender, the direct reflection from this window had to be eliminated since this would mask the reflectivity of the composition. A super hard, high efficiency anti-reflective coating was applied to the glass window. Its properties are illustrated in Figure 7. Since the coating is only anti-reflective in the visible part of the spectrum, the other frequencies had to be eliminated. Ultraviolet is absorbed by the coating and by the fiber optic also, but the near infrared was transmitted and highly reflected by the coating. Thus an infrared absorbing filter had to be inserted in the optical train between the light source and the fiber optics to eliminate this radiation. The characteristics of such a filter is illustrated in Figure 8. This filter has zero transmission from .75 microns out to 1.5 microns, transmits 70% of the visible energy and thus is ideally suited for this application. The last element in the optical train is the photo detector which is a silicon diffused, P-N junction, photovoltaic light sensor. Its spectral response is illustrated in Figure 9.

DISCUSSION OF RESULTS

The composition was tested in three different forms: in the dry state, in a water slurry and in an alcohol slurry. Known percentages of the composition such as 20% boron, 80% barium chromate for example, were prepared and the reflectivity of each was taken and recorded. A curve of reflectivity versus percentage composition was generated in each case.

Figure 10 and Figure 11 show the curve for the composition in the dry state. When a reflectance of 25% is recorded, these graphs will show that the composition is 12% boron and 88% barium chromate. Figure 12 illustrates the relationship between reflectivity and percentage composition for a mixture in a water slurry and Figure 13 for a mixture in an alcohol slurry. The composition is usually mixed in either water or alcohol slurries because this desensitizes the mixture and makes it much safer to handle.

Accuracies of 1% to 2% have been obtained in determining percentage of composition of an unknown mixture in the dry or powder state. In the two slurry forms accuracies of 2% - 3% have been obtained. These results were obtained with the mixture in a static condition. The final stage of the development, to determine when the mixture is homogenous, has not yet been completed. This will be done following the installation of a suitable pyrotechnic blender.

However, based on the results of a similar study conducted by IITRI, Figure 14 represents the output that one could expect from continuous monitoring of the boron-barium chromate mixture[1]. From time T_0 to T_1 there are wide fluctuations in the reflectivity, indicating that the mixture is not uniform. At time T_1 the fluctuations are eliminated indicating a uniform mixture. From time T_1 to T_2 the reflectivity gradually decreases and the mixture darkens due to the breaking up of the boron agglomerates. At time T_2, the reflectivity is stable indicating that the mixture is completely mixed and ready for use.

CONCLUSIONS

For the first time, a nondestructive testing technique has been developed to determine the correct percentage of composition of a boron-barium chromate pyrotechnic mixture. It is planned to complete the development following the installation of a suitable blender. The technique is inexpensive, automatic, and can be remotely operated whereas the performance testing technique is time consuming, inaccurate and expensive. Accuracies of 1% - 3% have been obtained in determining the percentage of composition in different dry and slurry forms. This same technique will be applied to other compositions in the future.

RICHARD J. FRISINA
Picatinny Arsenal
Dover, New Jersey

REFERENCE

(1) Harwood, C. F., IIT Report No. C6189, May 1970

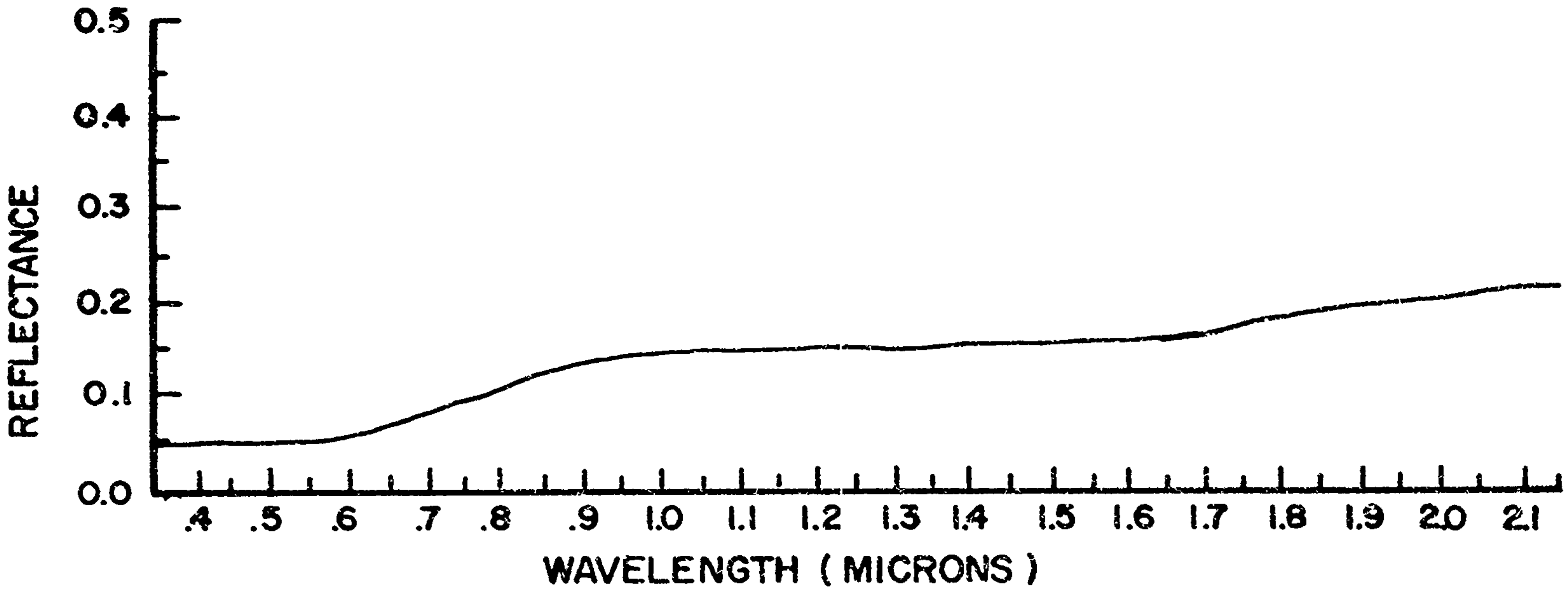


FIGURE I

REFLECTIVITY OF BORON VS WAVELENGTH

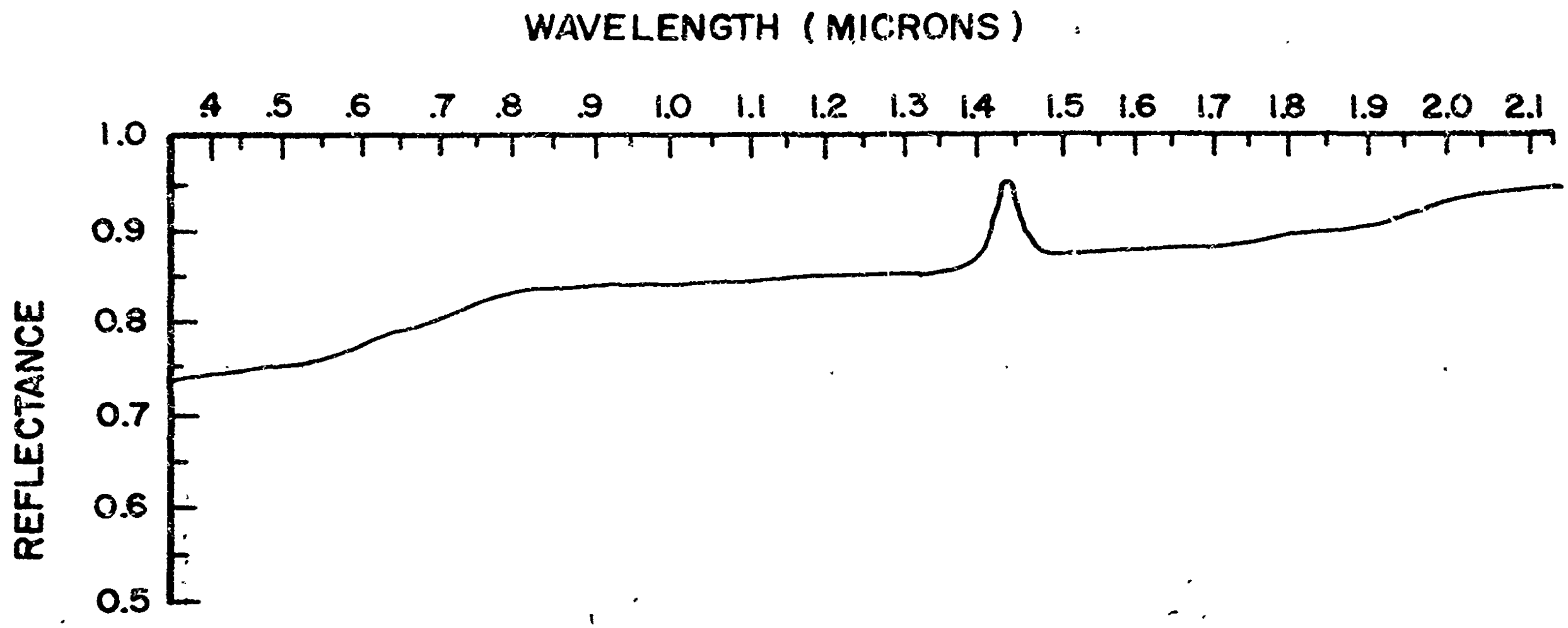


FIGURE 2

REFLECTIVITY OF BARIUM CHROMATE VS WAVELENGTH

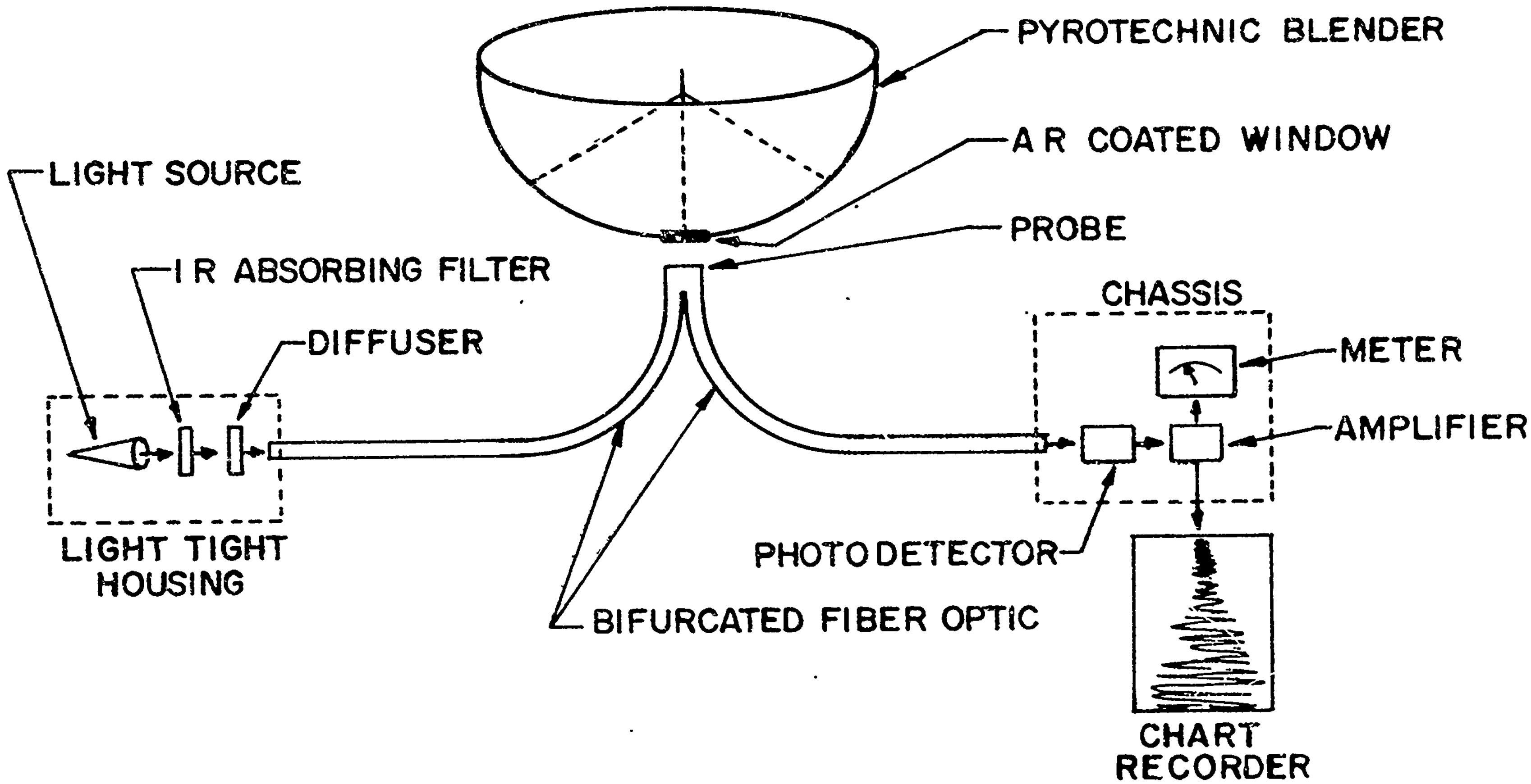


FIGURE 3

ILLUSTRATION OF TEST APPARATUS

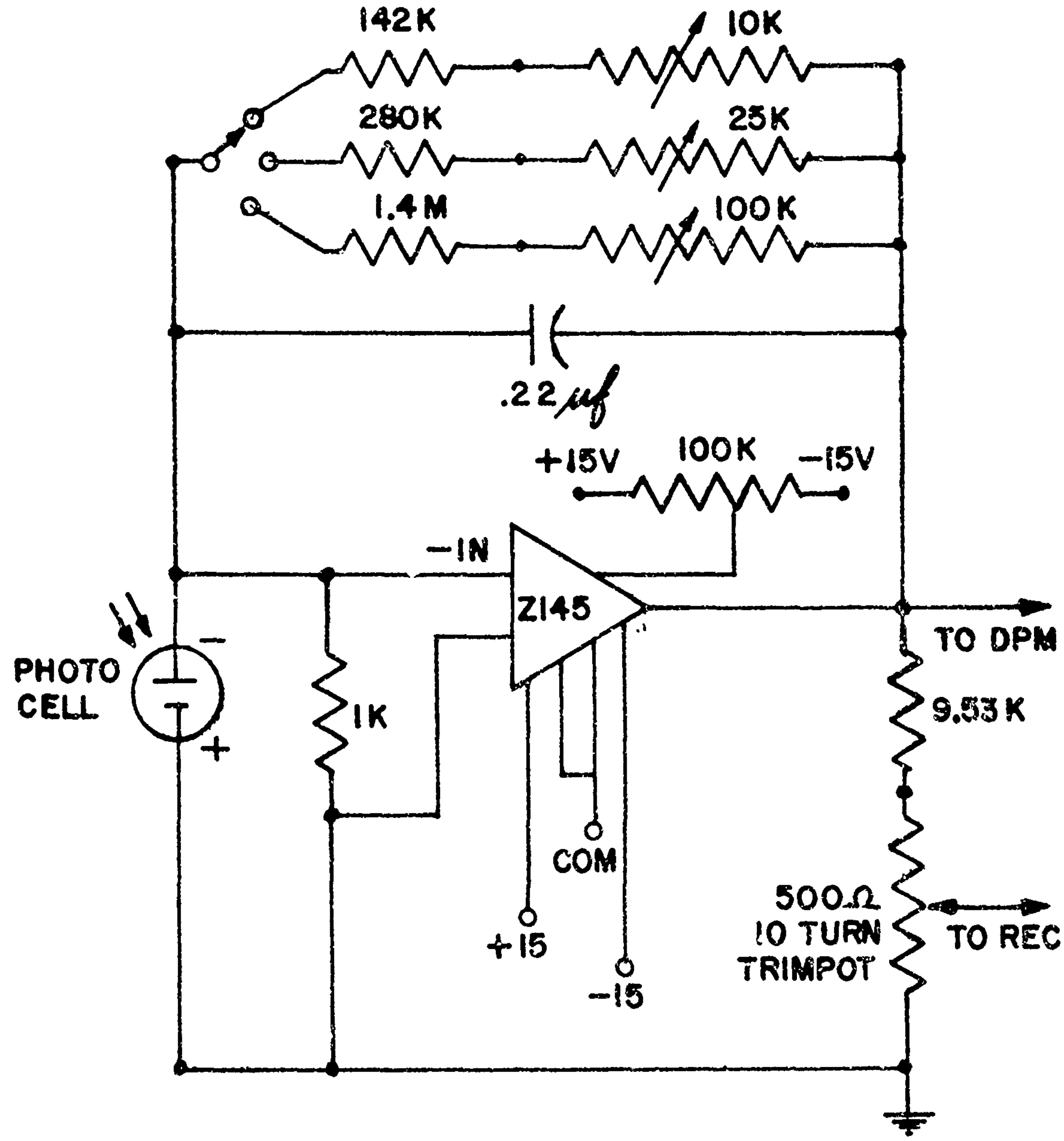


FIGURE 4

FIBER OPTIC PROBE AMPLIFIER

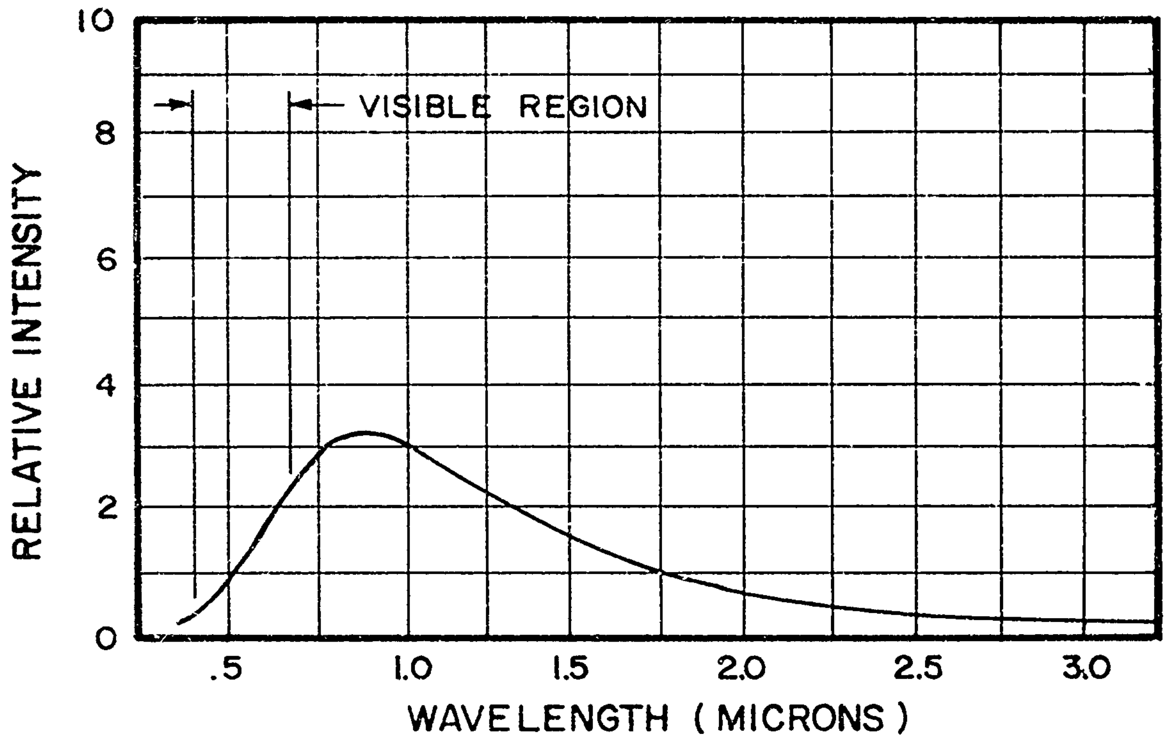


FIGURE 5

SPECTRAL ENERGY DISTRIBUTION OF TUNGSTEN AT 3000°K COLOR TEMPERATURE

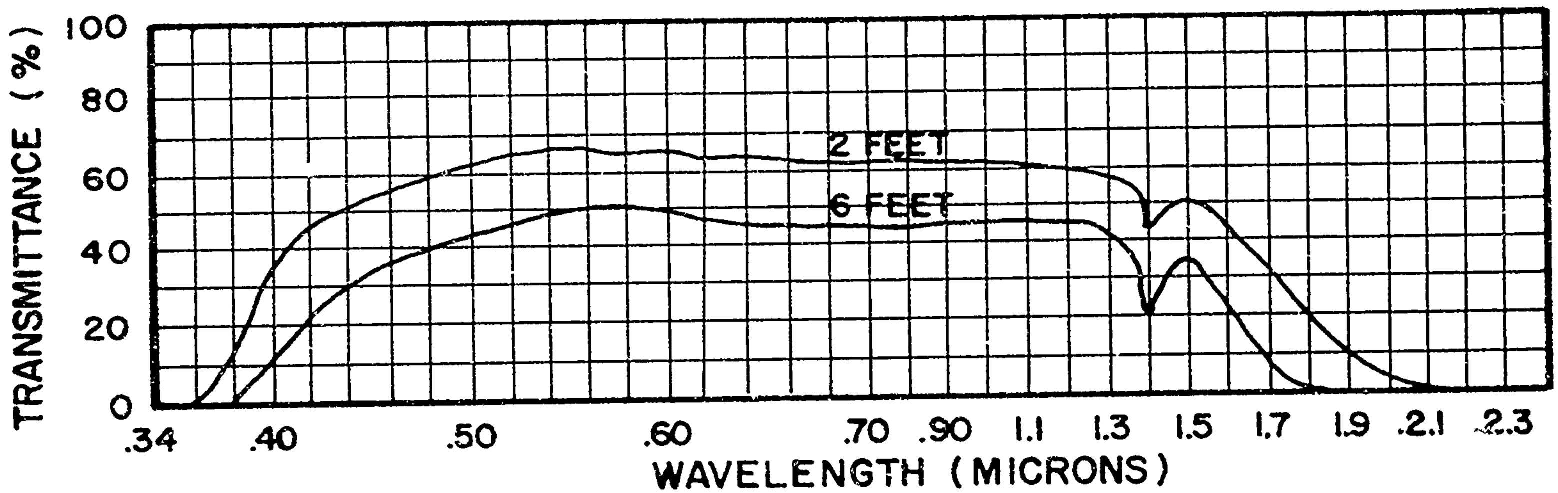


FIGURE 6

FIBER OPTICS TRANSMISSION VS WAVELENGTH

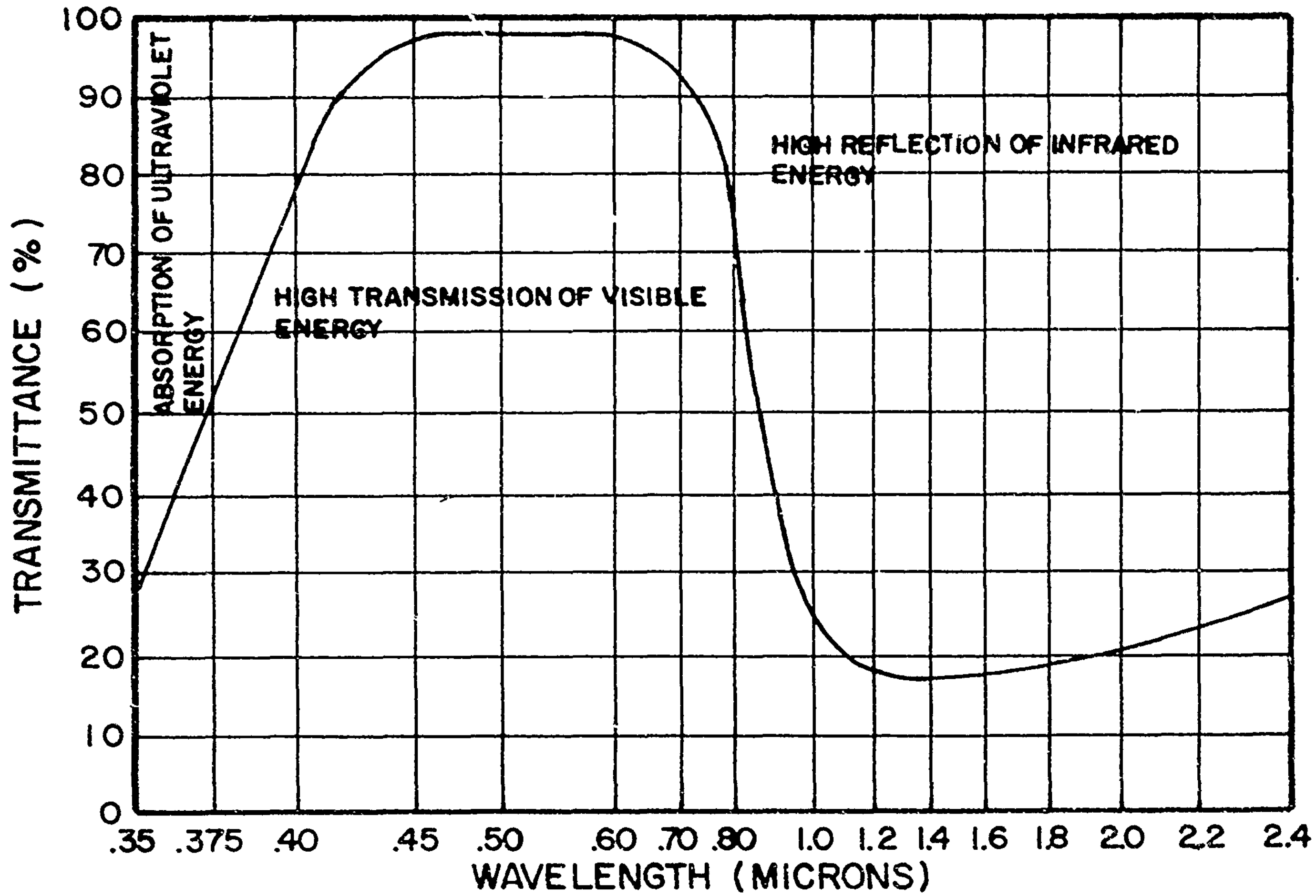


FIGURE 7

SPECTRAL PROPERTIES OF ANTIREFLECTIVE GLASS

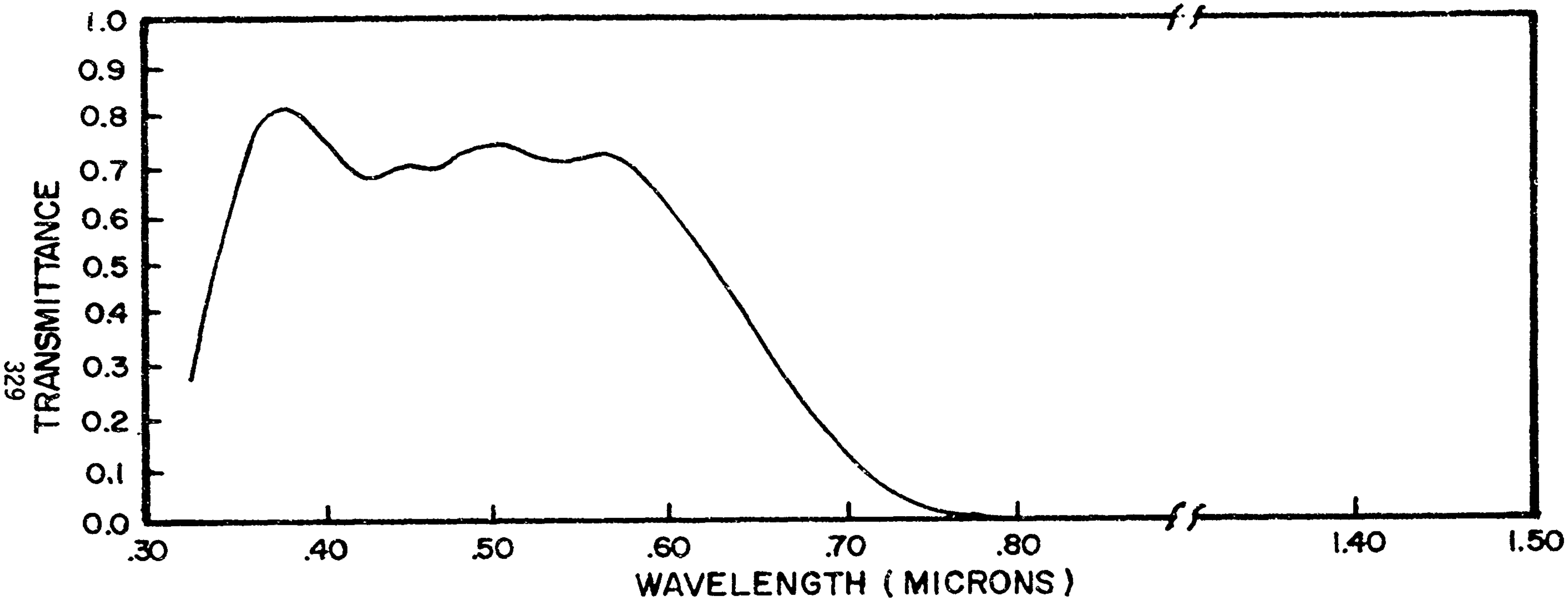


FIGURE 8

INFRARED ABSORBING FILTER TRANSMISSION VS WAVELENGTH

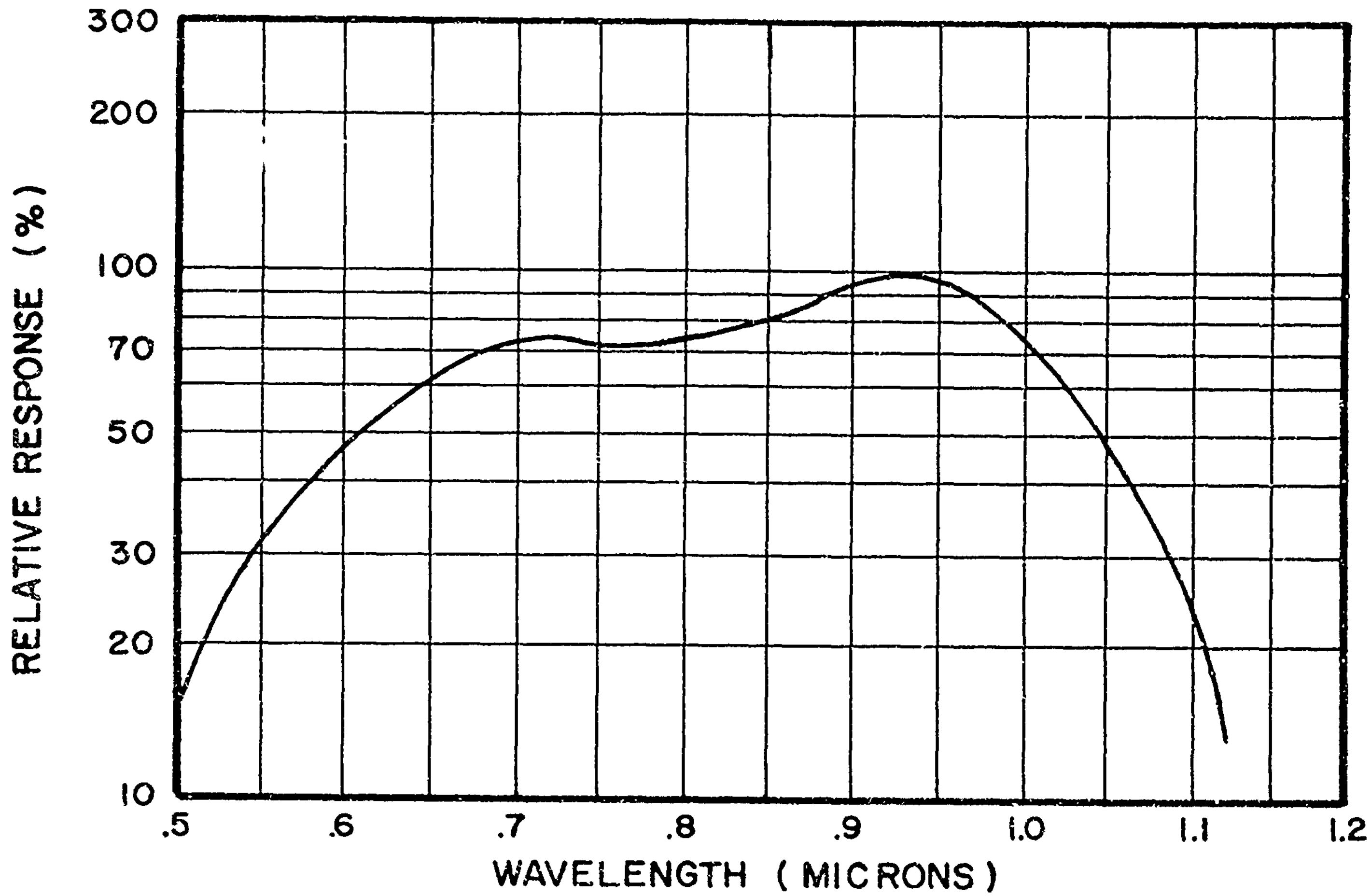
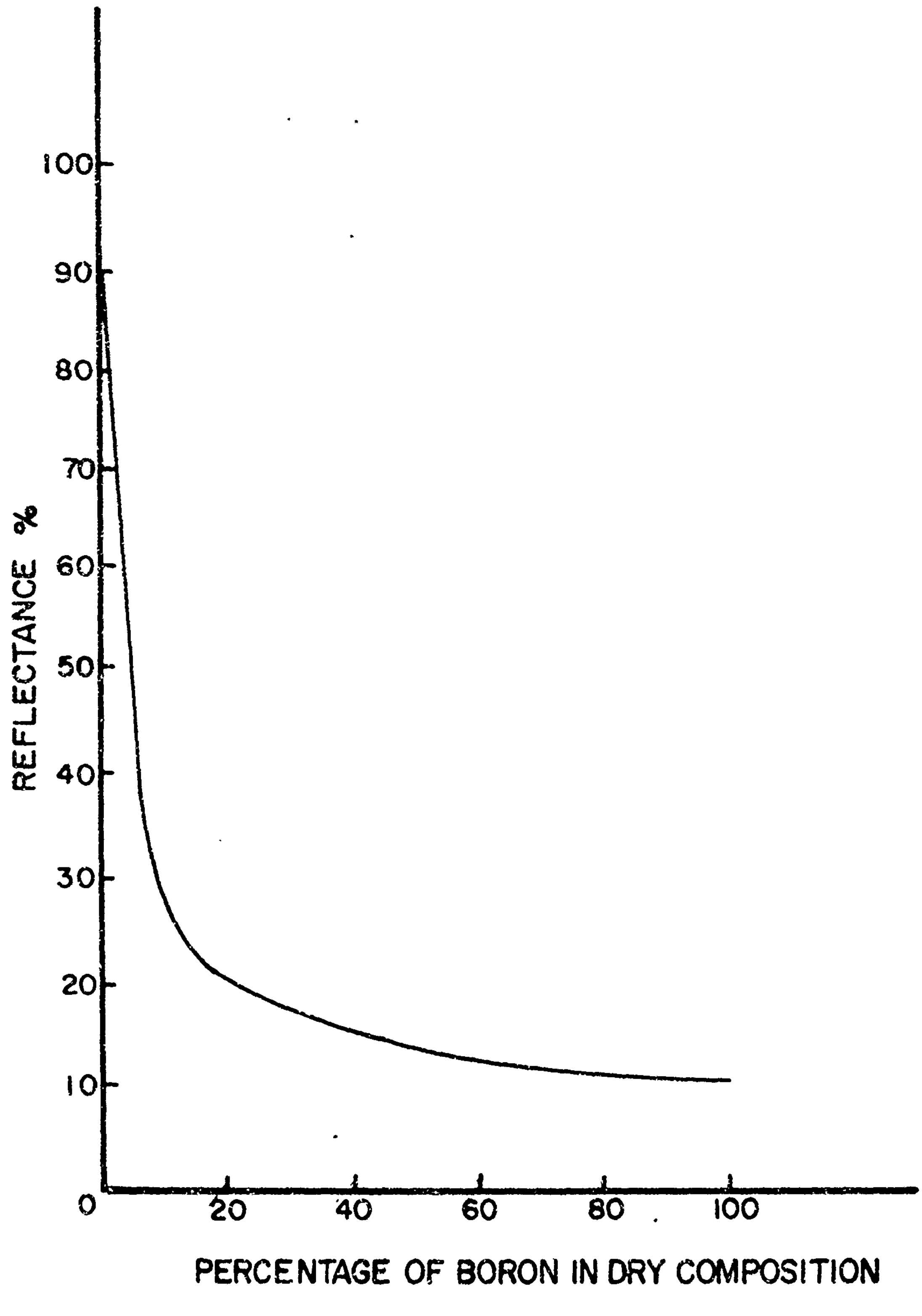


FIGURE 9

RELATIVE SPECTRAL RESPONSE OF PHOTOSENSOR



100
90
80
70
60
50
40
30
20
10
0
REFLECTANCE %
20
40
60
80
100
PERCENTAGE OF BORON IN DRY COMPOSITION

FIGURE 10

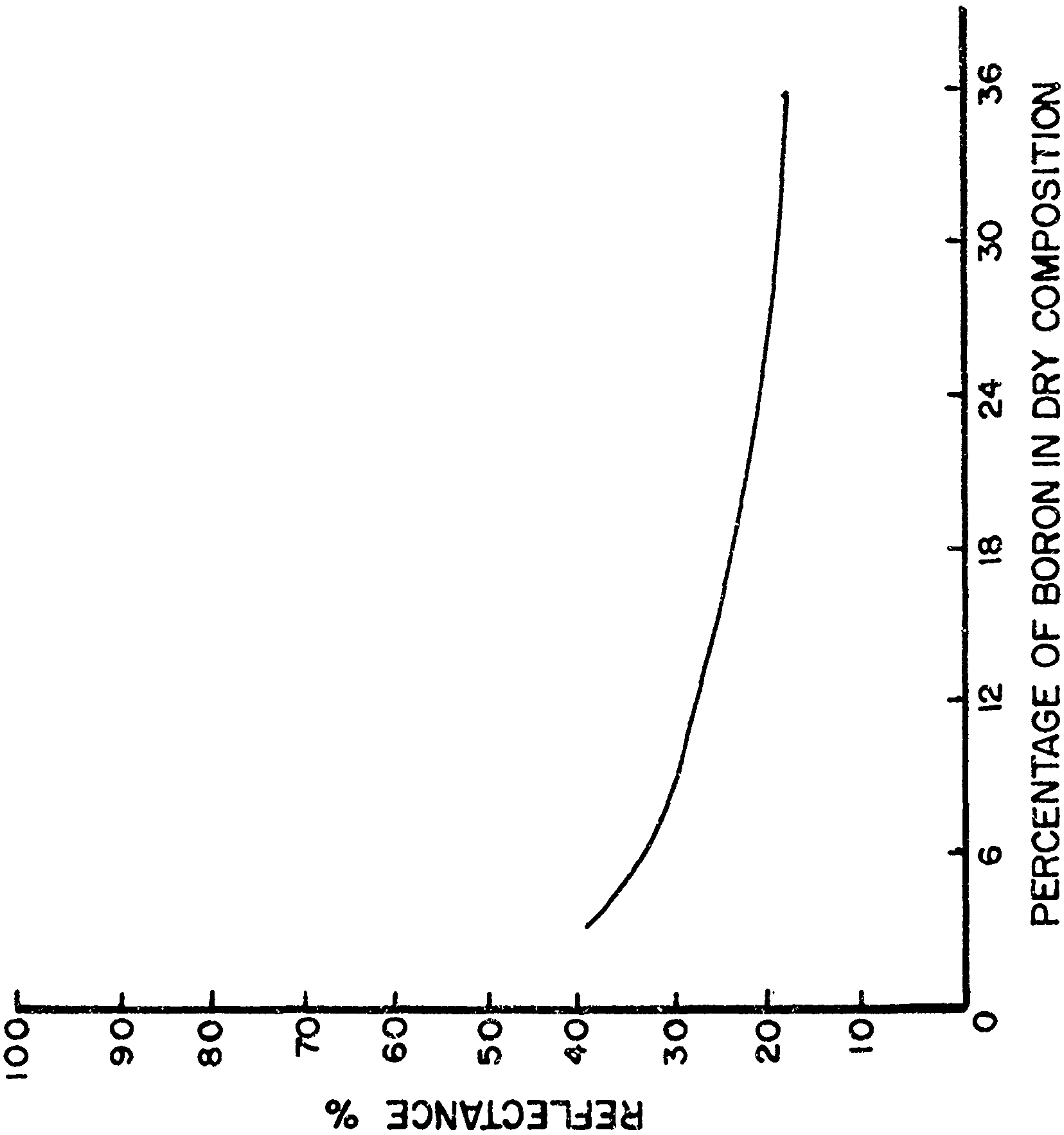

REFLECTANCE %
100
90
80
70
60
50
40
30
20
10
0
6
12
18
24
30
36
PERCENTAGE OF BORON IN DRY COMPOSITION

FIGURE 11

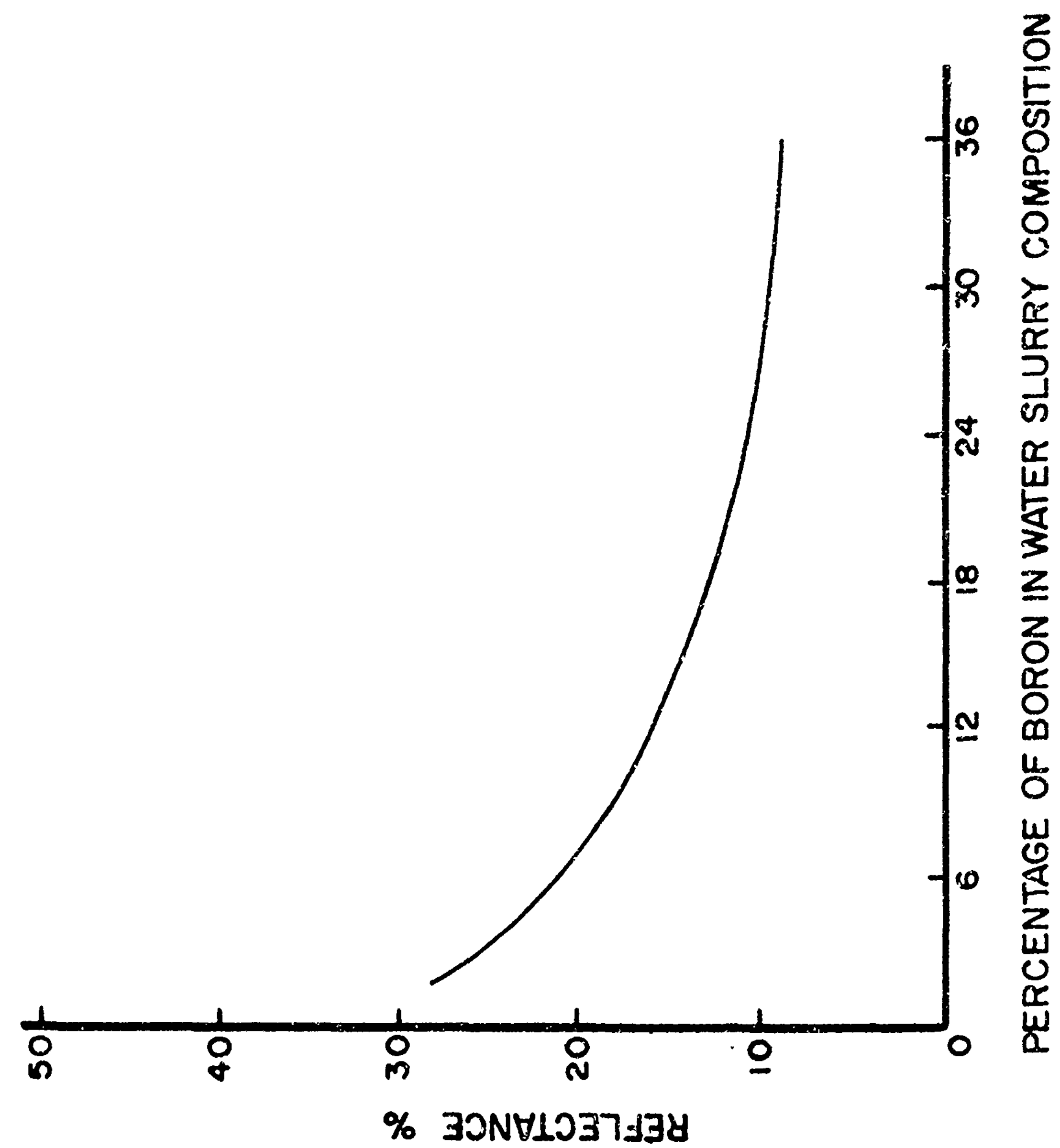
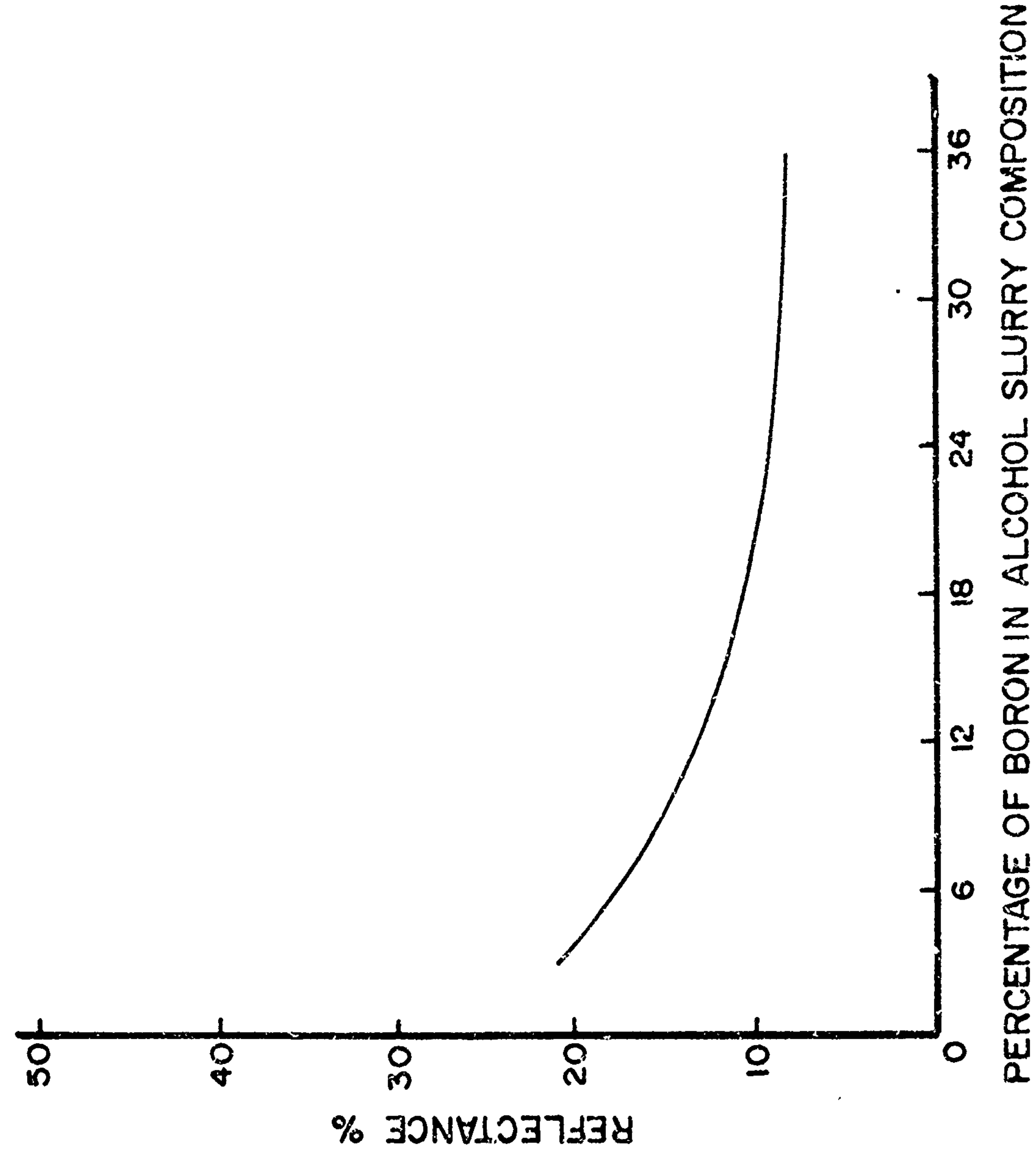
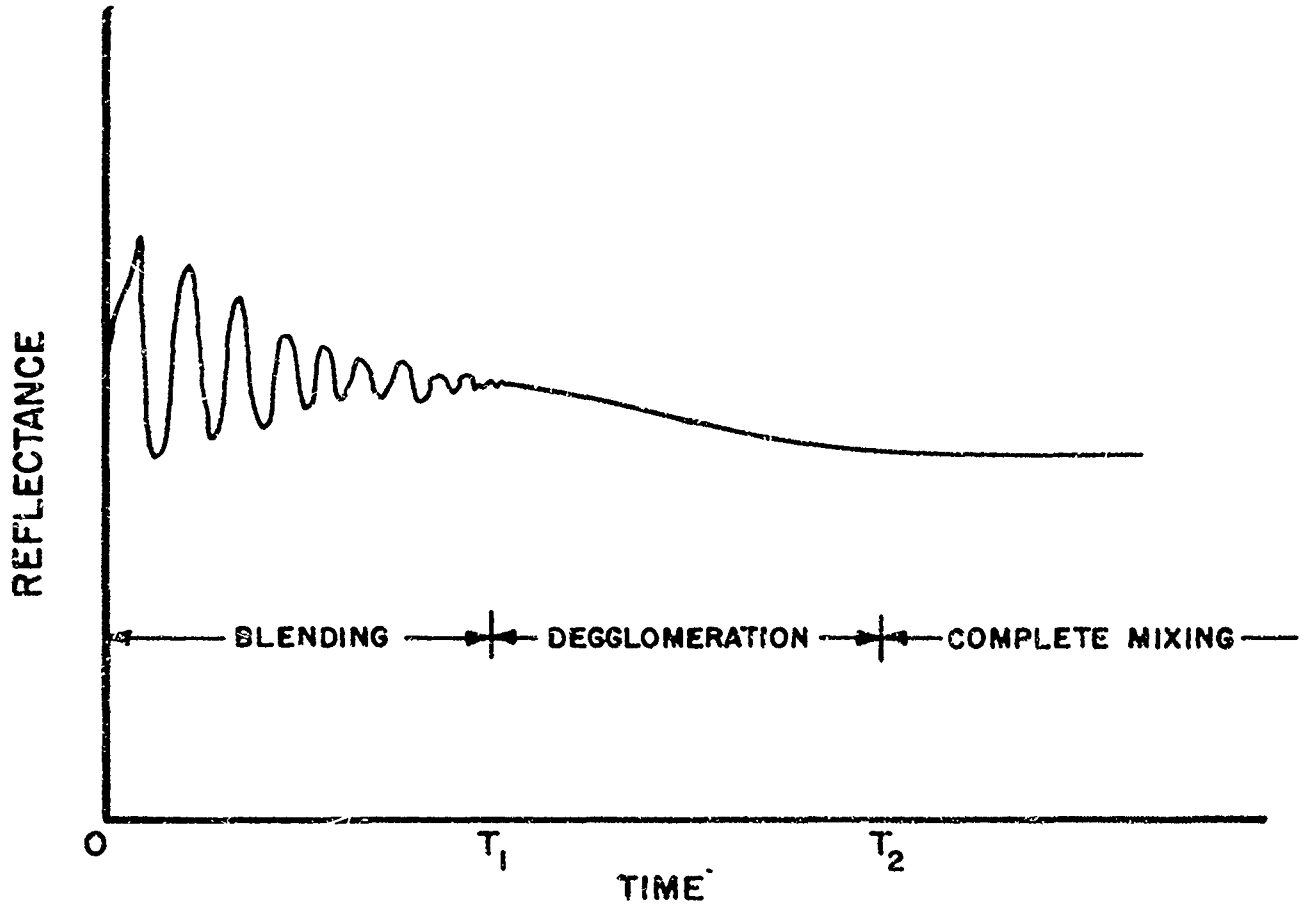

REFLECTANCE %
50
40
30
20
10
0
6
12
18
24
30
36
PERCENTAGE OF BORON IN WATER SLURRY COMPOSITION

FIGURE 12



REFLECTANCE %
50
40
30
20
10
0
6
12
18
24
30
36
PERCENTAGE OF BORON IN ALCOHOL SLURRY COMPOSITION

FIGURE 13



EXPECTED OUTPUT FROM CONTINUOUS MONITORING OF THE BORON-BARIUM CHROMATE MIXTURE

FIGURE 14

PAPER NO. 14

FOR PRESENTATION AT 20TH DOD NDT CONFERENCE

RUBBER TO METAL BOND INSPECTION

By

A. S. KRESS
Chief, Quality Engineering Division
Product Assurance Directorate
U. S. Army Tank Automotive Command

And

D. L. GAMACHE
Project Officer, Quality Engineering Division
Product Assurance Directorate
U. S. Army Tank Automotive Command

RUBBER TO METAL BOND INSPECTION

Important parts of the Army materiel inventory are components which contain rubber to metal bonds. Many of these items contribute significantly to the motive abilities of vehicles and thus are of intrinsic importance to a mobile Army. An adequate inspection to control the quality of the bonds in these parts is therefore an important part of the Army product assurance process.

Because the U. S. Army Tank Automotive Command (TACOM) is intrinsically involved in much of the procurement and use of rubber to metal bonded parts, it has been concerned with having a useable nondestructive rubber-metal bond test. This paper is a review of significant TACOM efforts in this area.

BACKGROUND

The standard Army inspection procedure for determining the acceptability of these adhesive bonds is a peel test performed in conformance to ASTM Specification Number D-429, Test for Adhesion of Rubber to Metal. Slide 1 shows a schematic illustration of the peel test as performed on a track shoe rubber pad. The primary disadvantage of the peel test is that it is destructive. Thus it dictates lot passage or failure on the basis of sample testing. Another disadvantage is the test monitors only bond condition in the area in between the two incisions. If an area outside the strip formed by the two incisions is locally unbonded or weak it will not be detected by the peel test. The peel test is also time consuming in preparation, machine attachment, and test execution. In addition the machine operator must be experienced in controlling load relief vs. rubber severing so that the total tensile load is low enough that the recorder pen can respond to small weak bond areas.

A nondestructive test, which can be performed on every part in a simple, inexpensive manner is highly desirable. TACOM has been looking for such a test. Highlights of this search are presented below. The work was performed by several different organizations. Some was performed in-house by the TACOM Product Assurance Directorate; some was performed on contract by the TACOM Product Assurance Directorate; some was performed by the TACOM Propulsion Systems Laboratory by direction of the Army Materials and Mechanics Research Center; some was done on a no-cost basis by industry in the form of short feasibility checkout.

TRACK PAD INSPECTION

The track shoe rubber pad is an important item in the Army materiel system whose utilization depends upon a good rubber to metal bond. The TACOM search for an applicable NDT technique is described relative to this item.

A nondestructive testing (NDT) technique is desired which will allow an accurate prediction of the bond quality of the adhesive layer between a piece of SBR rubber (about 1.5" thick) and a steel plate (3/16" thick). The rubber is bonded to one side of the steel plate which is partially flat and partially curved. Two configurations of tank pad are Army nomenclature T-130 and T-136 and are shown in Slide 2. The bond areas are approximately 24 square inches on the T-130 pad and 34 square inches on the T-136 pad.

Bond deterioration can occur at any of the available bond interfaces: rubber, adhesive, or steel. The adhesive used in each pad varies with the particular supplier. Dimensional tolerances are loose. Both debonds and understrength bonds can be a problem.

An ideal NDT technique which solves the bond problem will be applicable to a production test procedure. It will be reasonably fast and simple to perform. The present peel test takes 30 minutes. Also the inspection cost per pad with any test must be low because the pad cost is low (about $1.50 per pad.)

At the start of the effort to find an adequate test, several inspection methods were evaluated and discarded:

Holography - This technique was tried and found inapplicable because of basic geometric limitations. Static vacuum loading was used to study creep deflection. The results were negative because of the thickness of the rubber. This same thickness precluded use of either thermal or dynamic loading.

Infrared (Passive) - Track pads with debonds in them were heated with hot air and inspected with a infrared television type detection system. The results were non-reproducible and inconclusive. The approach was abandoned.

Infrared (Active) - The above track pads were scanned by a moving laser spot. The resulting heat build-up was monitored with the scanning infrared system. The results were again inconclusive, and the approach was abandoned.

Shock Testing - The vibration induced in track pads by a sharp impulse was monitored. The difference in the resulting vibration was monitored in an attempt to see the difference between a pad with little bonding and one with a good bond. The test was not successful because of pad-to-pad geometry variations.

In spite of these early unsuccessful tries at inspection approaches, two successful inspection techniques have been demonstrated. A hydrostatic proof test and an ultrasonic inspection have been shown applicable to track pad testing. The following is a description of these tests.

HYDROSTATIC TEST

Slide 3 schematically illustrates the test which consists of the following procedure:

(1) A pad is placed in a specially designed fixture. Nipple fittings admit pressurized water on the steel side of the pad at the plate sprue holes.

(2) The water is pressurized to 1000 psi and held for a period of two minutes.

(3) The pad is judged acceptable if no bulges or catastrophic failures occur. A catastrophic failure is a complete failure of the adhesive bond which allows a continuous passage for water to escape out the sides of the pad.

The hydrostatic test procedure has several advantages over the peel test. The paramount is that it does not destroy an acceptable pad. The procedure is also rapid and eliminates any operator anomalities. Slide 4 shows test fixtures used to apply the required water pressure. Slide 5 shows the system testing a pad.

An analytic comparison of the standard peel and the new Hydrostatic test shows that the tests are roughly equivalent. Experimental data verified this. The data shows that the hydrostatic test reproduces the peel test within 99% for T-130 pads and 87% for T-136 pads. Geometric considerations (sprue hole size and location) account for the discrepancy in results.

An economic estimate shows that the hardware involved in the peel test costs approximately ten times as much as that in the hydrostatic test. The cost per test is approximately six times more for the peel test than for the hydrostatic test.

The excellent correlation between peel and hydrostatic testing of the T-130 pads, and the cost savings involved, allows the recommendation that this test be used for production acceptance of T-130 pads. The data with the T-136 pads shows that the test is not yet optimal for these pads. A lower water pressure will

reduce the severity of the test and improve correlation with the peel test. The present T-136 test is good enough to justify the test for production control.

The hydrostatic test has been incorporated into a recent production contract as a control test.

While this test is a success, a quick and simple "non-proof test" inspection is still required. A test which can inspect the pad bond not only in the area around the sprue holes but in the areas removed from the sprue holes is needed. Also a test which does not require special fixturing, or the time to place the samples in the fixturing, is desired. Thus the TACOM search for an NDT approach continued.

ULTRASONIC TEST

High Frequency

Ultrasonics can locate the presence of debonds in the rubber-adhesive-steel interface area because voids which are characteristic of debonds provide a different acoustic impedance that the rubber or adhesive present when there are no voids. Mathematics shows that sensing for reflected energy from steel-rubber interface back at the steel insertion surface provides a 16% signal variation depending upon whether the ultrasonic beam is reflected off a steel-air interface or a steel-rubber interface. This is enough to tell whether debonds are present or not.

It is necessary to inspect ultrasonically from the steel side of the pad using reflection. The measuring signal must be kept inside the steel plate because any measurement technique which sends a signal through the rubber will

be subjected to the high sonic attenuation effects of the rubber. The latter will effectively reduce the sensitivity of the inspection to an unuseable level.

A contact pitch-catch ultrasonic configuration was therefore used in evaluating this testing method. A 5.0 MHz dual element transducer was water coupled to the pads, and hand scanned across them. A commercial ultrasonic instrument was used to exite the transducer and to analyze the return signal. To quantitatively measure the amount of signal present in the instrument's electronic gate, a digital voltmeter was connected to the recorder output of the instrument.

Comparison between the resulting ultrasonic data and subsequent peel test data shows that the test gave an ultrasonic indication from a pad whose bond strength was below 110 pounds. For convenience this can be defined as the "good" pad acceptability limit. Using this criterion, the ultrasonic technique was 100% successful in determining the presence of good or bad bonds for a group of 25 pads which were taken from storage and inspected.

Comparison graphs for two pads are shown in Slides 6, 7, 8 and 9. The reciprocity of the curve shapes is evident. The increase in electrical output for a poor bond versus a good bond agrees with the theory which predicts a poor bond would have more air in its bond line than a good bond. The resulting increased impedance mismatch causes longer signal ringing and more signal in the electronic gate.

This preliminary work now requires follow-up testing on new pads and then large scale testing to fully evaluate the technique's potential.

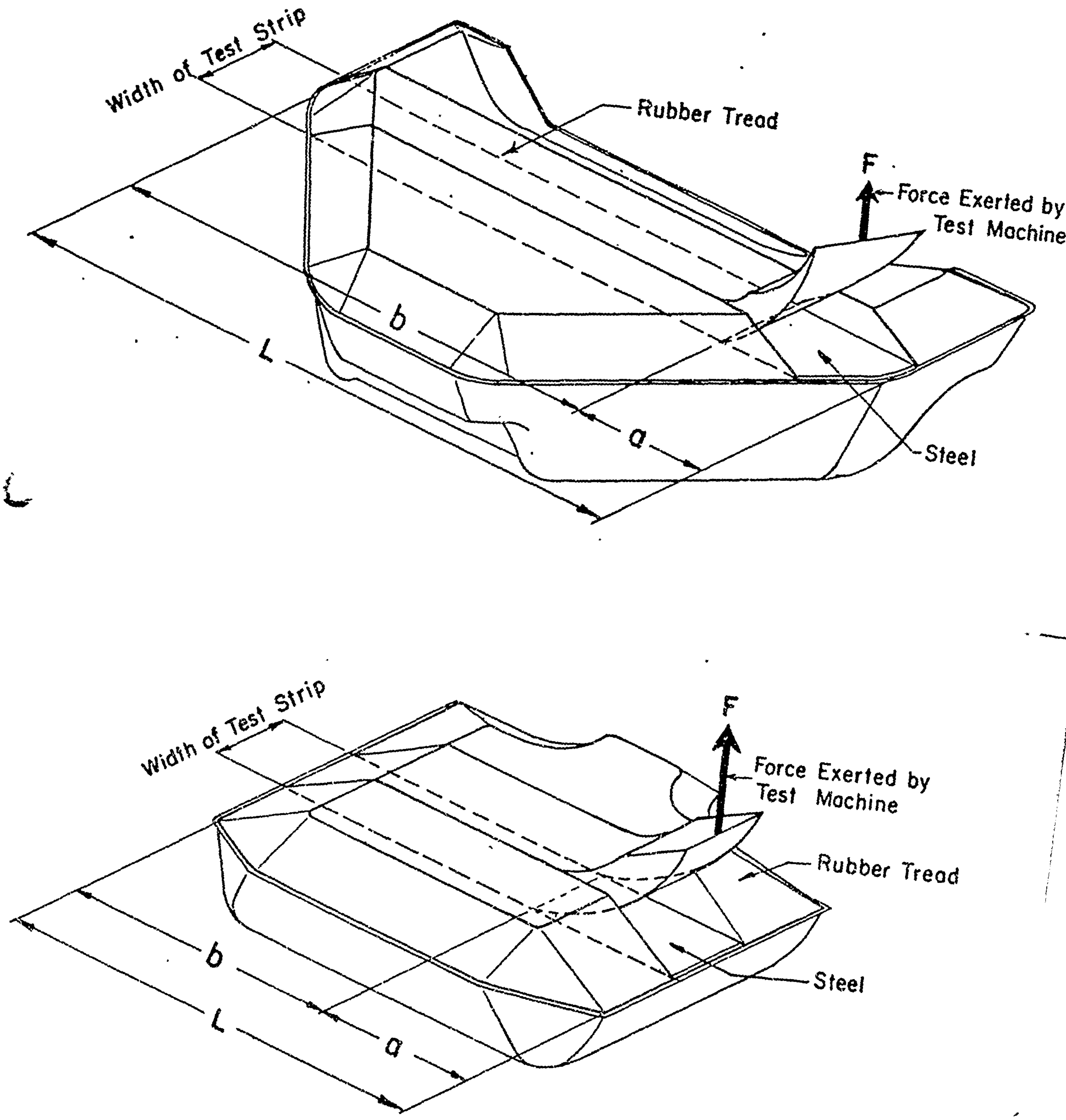
Low Frequency

A second avenue of ultrasonic testing is being investigated by TACOM personnel. This approach is called "acoustic spectrometry". It is based upon measuring the change in the acoustic characteristics of an oscillating piezoelectric crystal due to the damping characteristics of bonding at the rubber-metal interface. Initial results are just now being achieved. It is too early to determine the success potential of this approach.

SUMMARY

TACOM is pursuing solutions to the problem of rubber-metal bond quality determination. In the area of track pad inspection TACOM has developed a workable proof test based on hydrostatic pressure. It is continuing to search for an acceptable nondestructive inspection technique. Both high and low frequency ultrasonics are being investigated. The low frequency work is preliminary at present. A high frequency ultrasonic inspection has been developed which works successfully on pads from depot storage. Work is required to determine its utility on new pads, and then large scale testing is required to fully evaluate the technique's potential.

A. S. Kress / D. L. Gamache
Product Assurance Directorate
U. S. Army Tank Automotive Command
Warren, Michigan 48090



SCHEMATIC ILLUSTRATION OF PEEL TEST.

Fig. 1

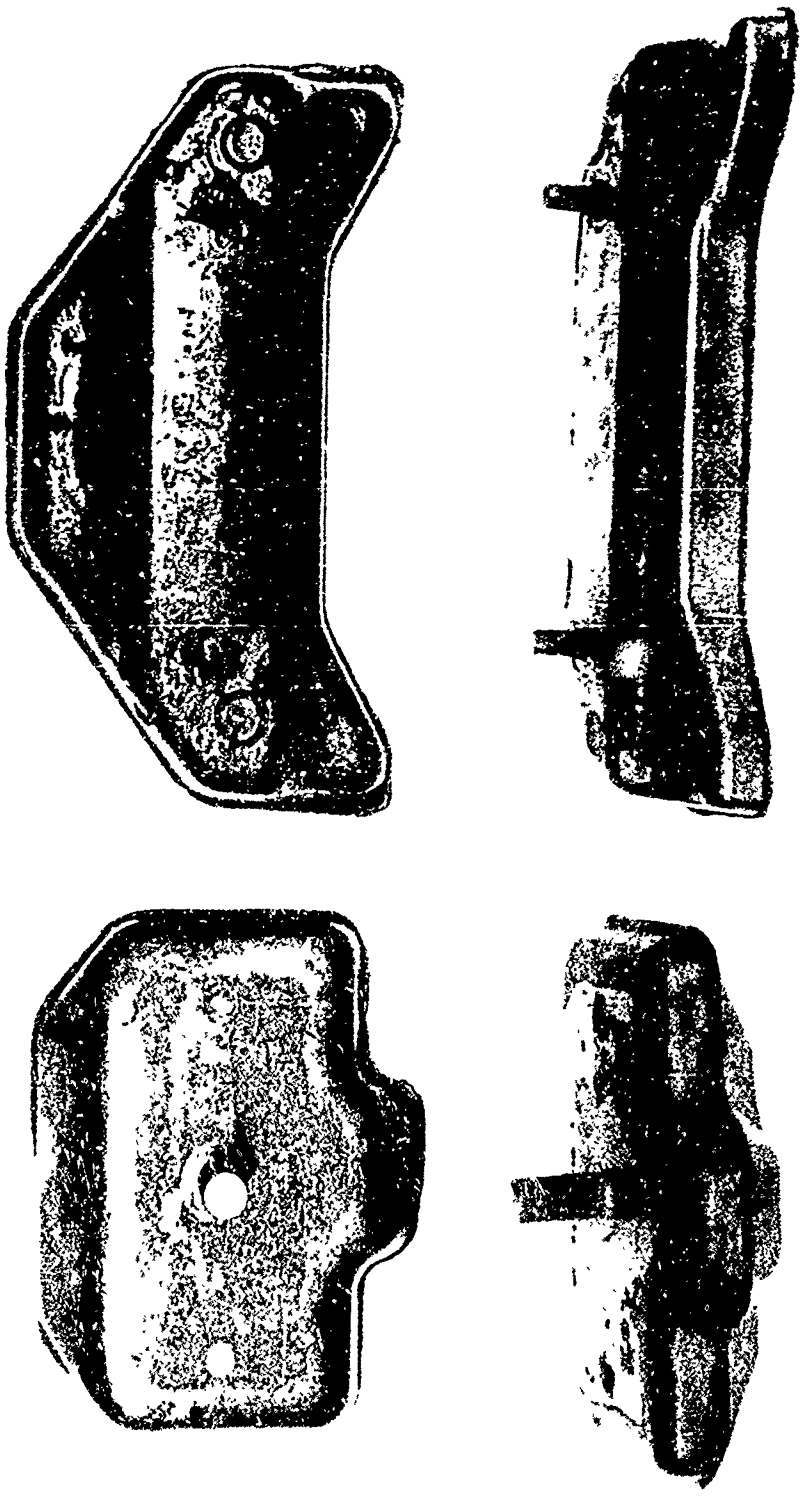
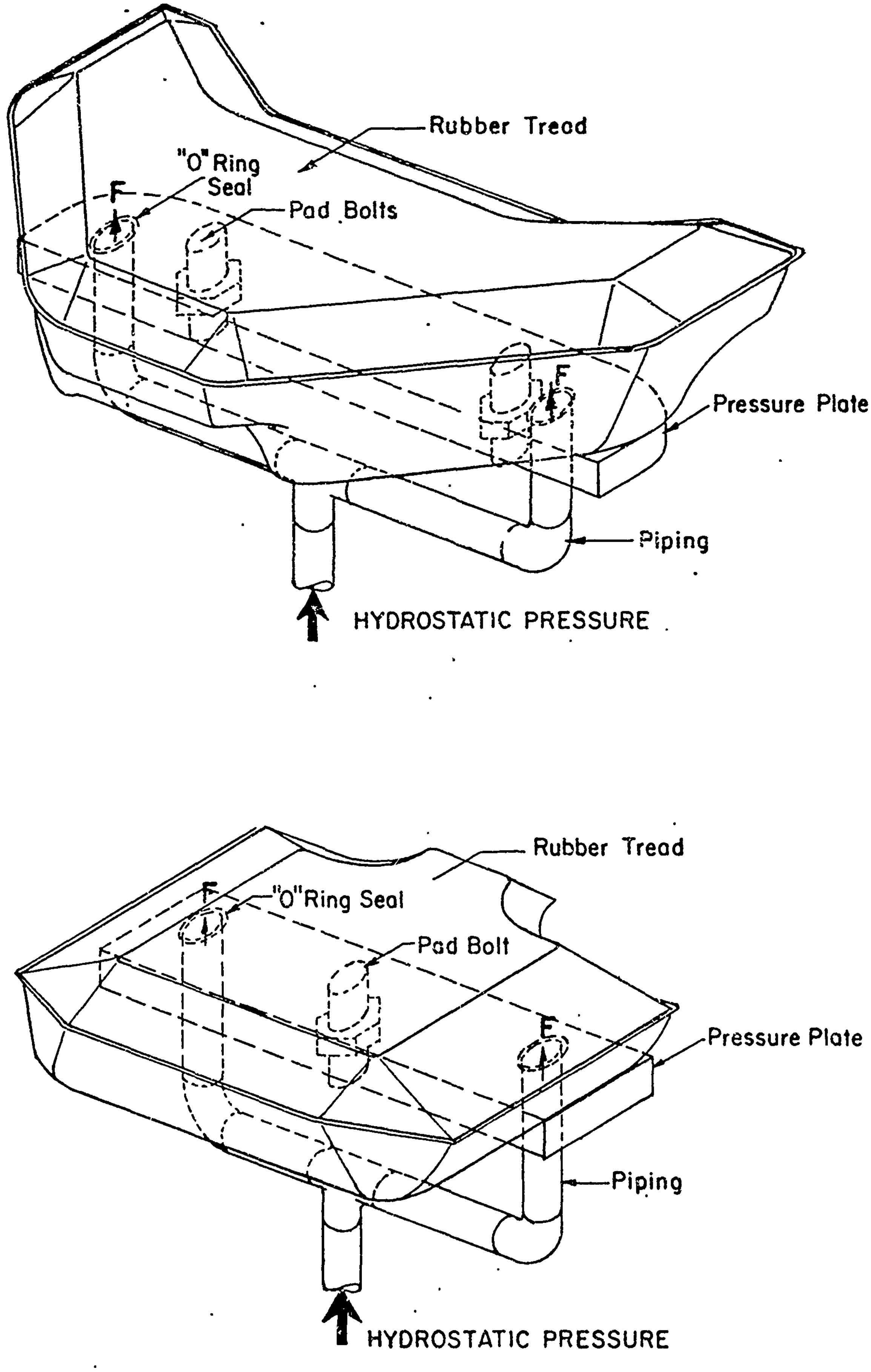


Fig. 2



SCHEMATIC ILLUSTRATION OF HYDROSTATIC TEST.

Fig. 3

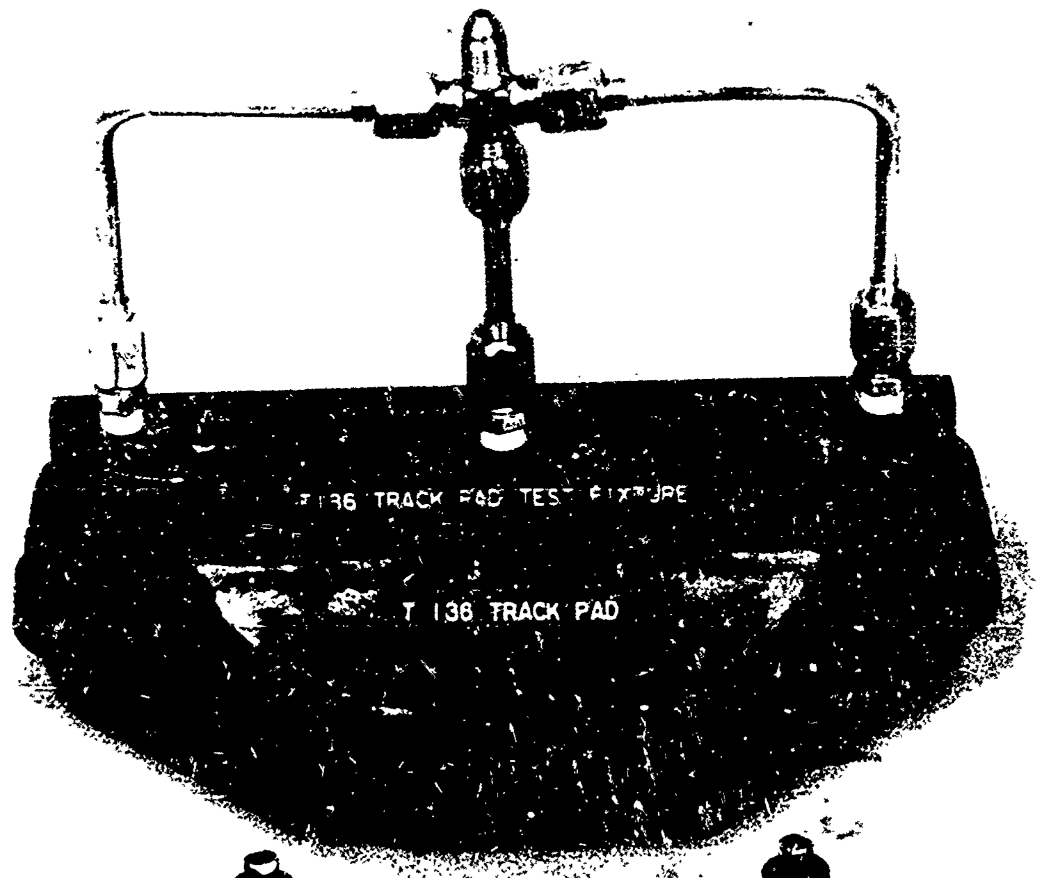

T 136 TRACK PAD TEST FIXTURE
T 136 TRACK PAD
T 130 TRACK PAD TEST FIXTURE

Fig. 4

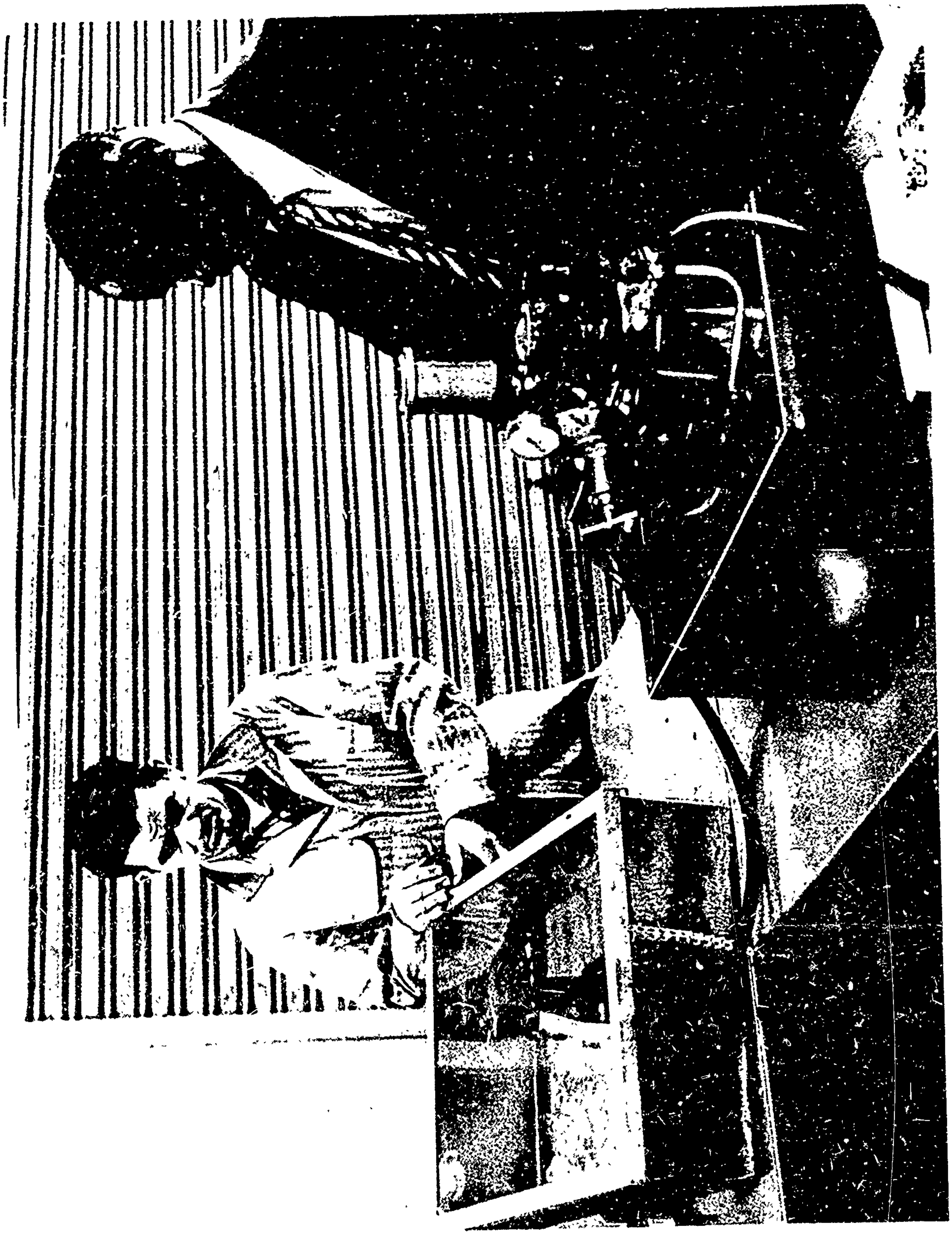


Fig. 5

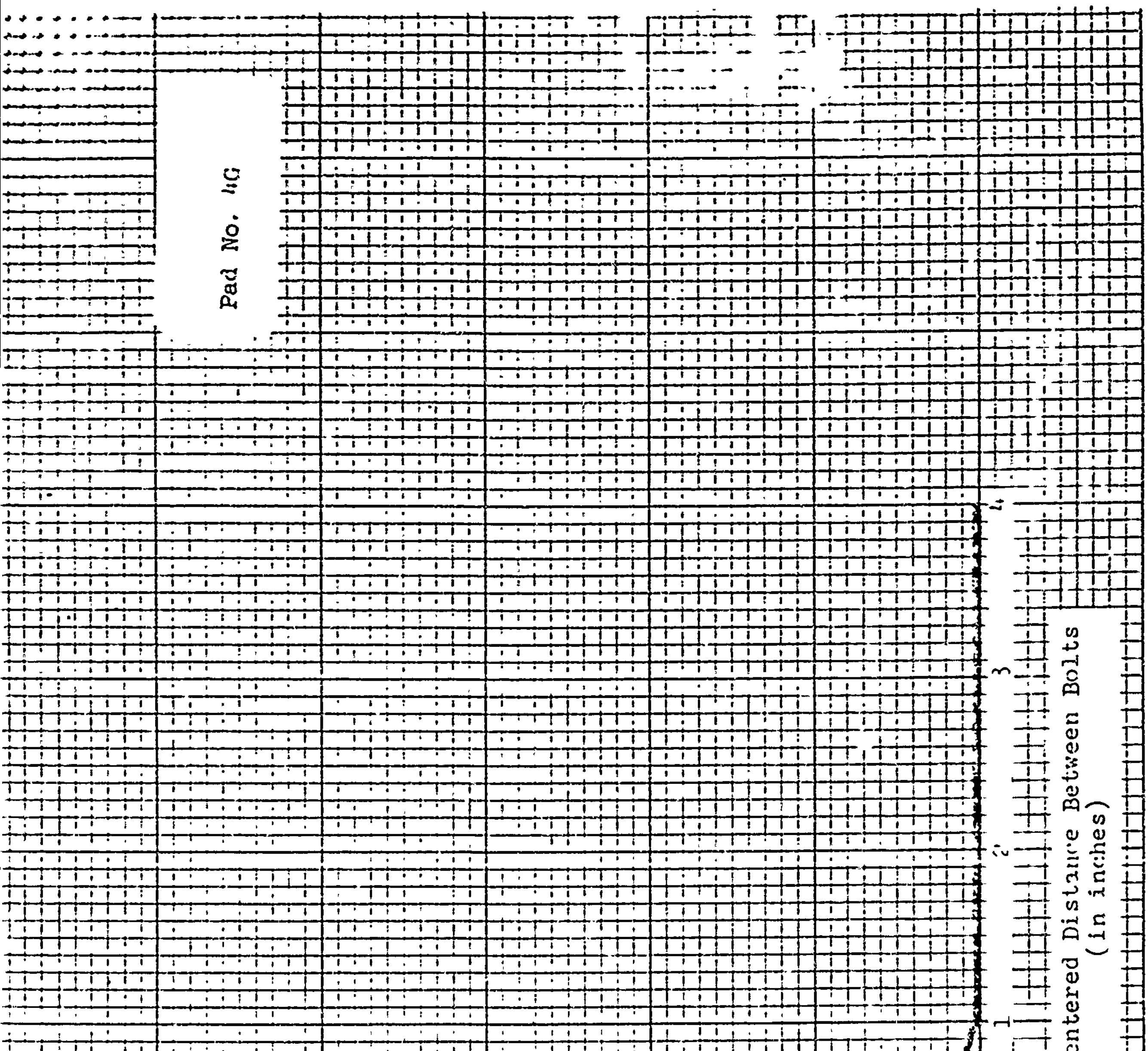
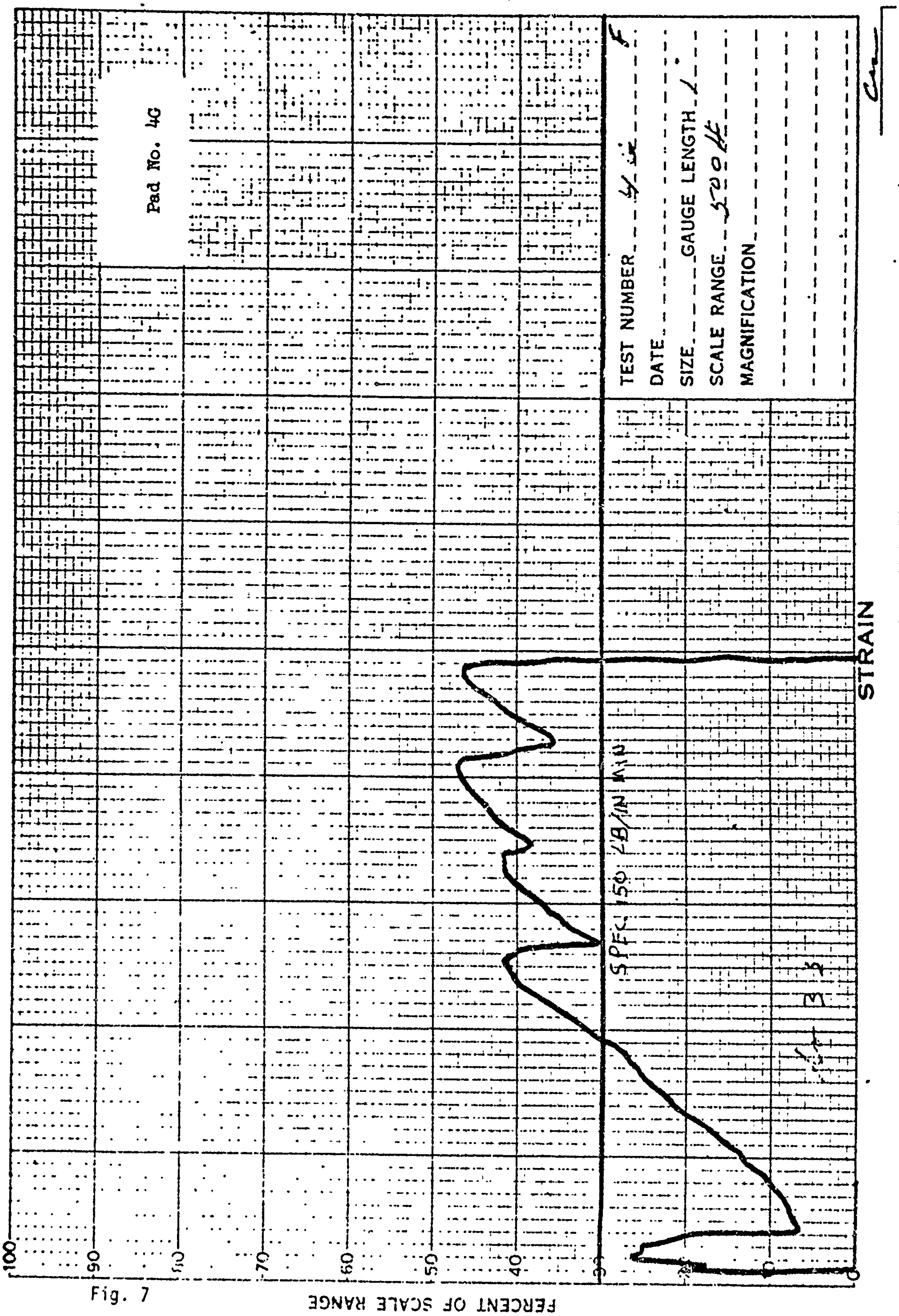
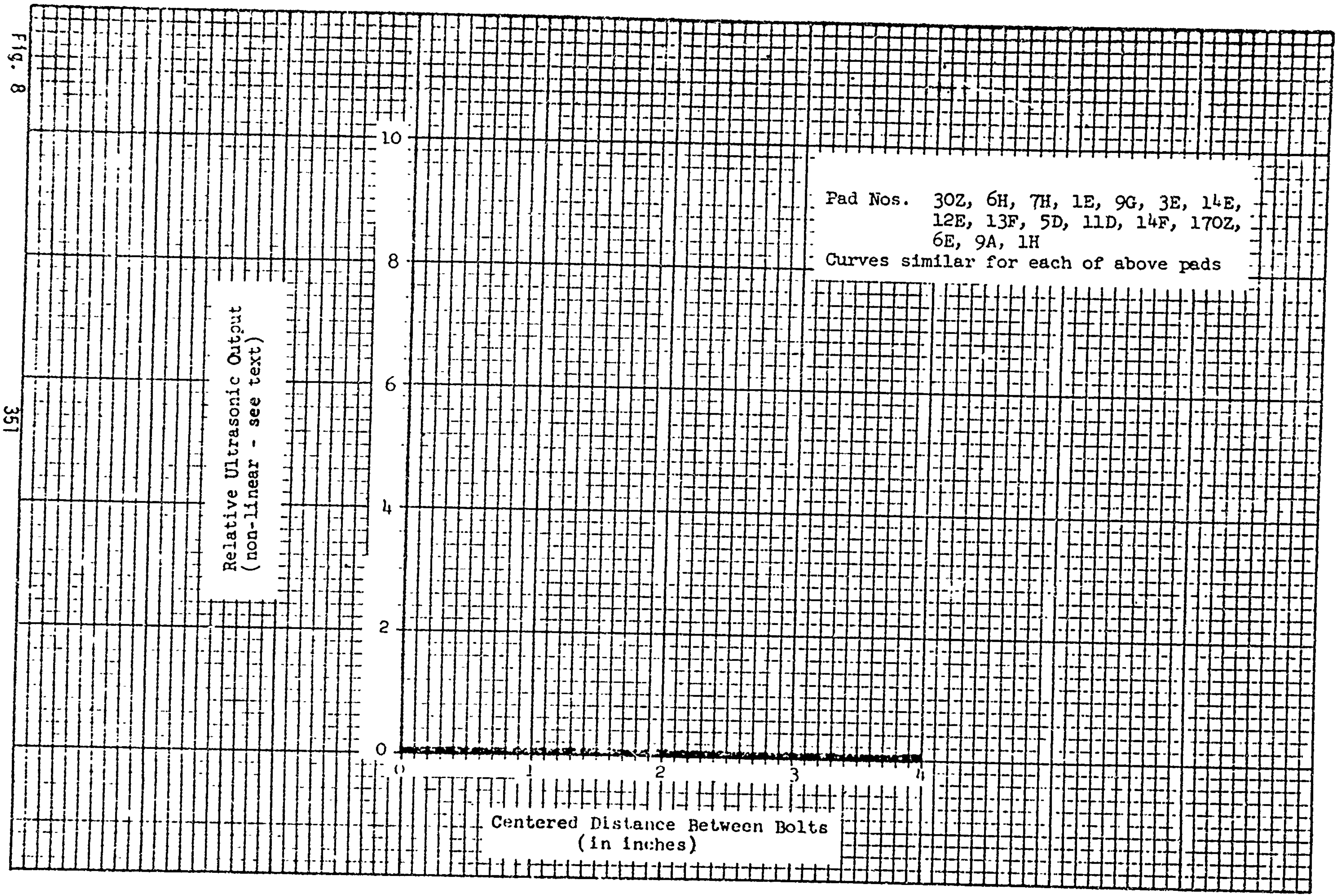

Pad No. 4G
Relative Ultrasonic Output
(non-linear - see text)
10
8
6
4
2
0
1
2
3
4
Centered Distance Between Bolts
(in inches)

Fig. 6



Pad No. 4G
TEST NUMBER
DATE
SIZE
GAUGE LENGTH
SCALE RANGE
MAGNIFICATION
STRAIN
DIVIDE BY MAGNIFICATION RATIO
No. 35-155
LOAD
PERCENT OF SCALE RANGE
100
90
80
70
60
50
40
30
20
10
0
SPEC 150 LB/IN MIN

Fig. 7



Pad Nos. 30Z, 6H, 7H, 1E, 9G, 3E, 14E, 12E, 13F, 5D, 11D, 14F, 170Z, 6E, 9A, 1H
Curves similar for each of above pads
Relative Ultrasonic Output (non-linear - see text)
Centered Distance Between Bolts (in inches)
0
2
4
6
8
10
1
3

Fig. 8

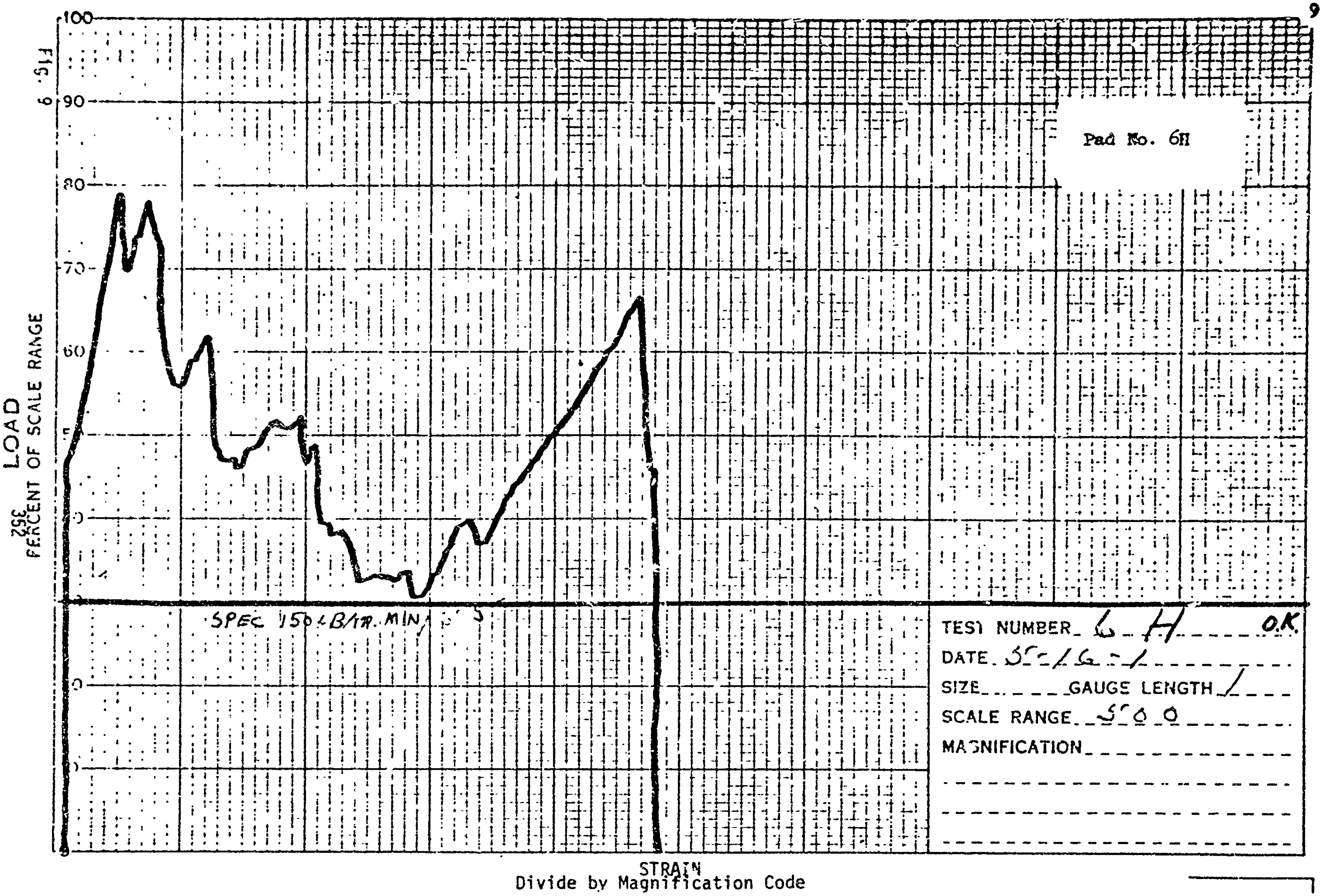

100
90
80
70
60
LOAD
PERCENT OF SCALE RANGE
Pad No. 6H
SPEC 150 LB/IN. MIN
TEST NUMBER 6 H O.K.
DATE 5-16-1
SIZE GAUGE LENGTH 1
SCALE RANGE 500
MAGNIFICATION
STRAIN
Divide by Magnification Code
No 35-155

Fig. 9

APPENDICES

PROBLEM: "Heat Retention Test of Canteen, Water, Insulated."

Feedback by: Morris L. Budnick, Army Natick Laboratories, Natick, Massachusetts.

The current heat retention test of the insulated water canteen has two time-consuming and undesirable requirements. The first is that the heat retention test takes 3 hours and 15 minutes per canteen. The second is that the canteen, after complete fabrication, shall be stored for 30 days prior to conduction of the test. The test consists essentially of checking the drop in temperature of hot water after the above specified time. It was determined that there is a direct correlation between the drop in water temperature and the rise in the temperature of the outer shell. An infrared non-contact radiometer was used to determine the rise in temperature of the outer shell within a specified time and these data compared with the results of the current heat retention test. It has been established that the insulated water canteen conforms to the heat retention test requirements if the rise in temperature of the outer shell is not greater than 5 degrees Centigrade in 8 minutes. Work is in process to determine if the 30-day storage requirement can be eliminated.

PROBLEM: "Evaluation of Hardwall Shelter Panels for Delaminations."

Feedback by: Morris L. Budnick, Army Natick Laboratories, Natick, Massachusetts.

The current method to evaluate hardwall shelter panels for delaminations is the tap test. This method is subjective and not reproducible. An evaluation using optical holography with vacuum stressing indicated that delaminated areas over 1 inch in diameter can be detected with virtually 100 percent accuracy, that defects from 1/2 inch to 1 inch in diameter can be detected with good accuracy, and that defects 1/2 inch or smaller in diameter are at the lower limit of sensitivity. It was established, however, that the rate of test is too low. The current requirement is to test not less than thirty panels, 8 inches by 13 inches, both sides in approximately 8 hours. A special panel was made with twenty-five delaminations in each face. The delaminations vary in size from 1/2 inch to 2 inches and are randomly scattered. This panel will be used in a three-way evaluation. The first evaluation will be made using ultrasonics, specifically the Lamb wave technique. The second evaluation will be made using optical holography with vibration stressing. The third evaluation will be made using ultrasonics with the couplant applied by either spray or a bubble. The airdrop platform which is similar to the hardwall shelter panel will be evaluated concurrently using the vacuum ultrasonic techniques.

PROBLEM: "Determination of Presence and Degree of Preferred Orientation in Copper Cones."

Feedback by: Domenic J. Molella, Picatinny Arsenal.

Solutions suggested:

Steve Hart, NRL - Determine ultrasonic shear wave velocity differences.

Robert Brockelman, AMMRC - Use of ultrasonic reflectivity measurements.

Status: Picatinny has developed a successful X-ray diffraction computerized Pole Figure Technique, but this technique is destructive. It is hoped that funding will be received to evaluate the ultrasonic shear wave velocity technique. As-spun and fully annealed cones have been furnished to Steve Hart, NRL, to determine feasibility of using above technique.

PROBLEM: "Nozzle Exit Cone for Rocket Motors."

Feedback by: John E. Lien, DCASR, Los Angeles.

Mr. Lien gave a preliminary status report of some of the feedback on this problem. More is planned for later conferences.

PROBLEM: "NDT Inspection of the R1820 Master Rod Bearing."

Feedback by: Joseph F. Cipriani, NAVAIRDEVCEN.

I would just like to take a few minutes of your time to tell you about our unique program sponsored by AIR-52055, under the capable direction of Jay Stevens, and one of the problems we tried to solve under the program.

About the 3rd of June, I received a phone call at NADC from the Metallurgical Lab in Pensacola regarding a problem they were having with the master rod bearing of the R1820 engine. Within 48 hours, we had a team in Pensacola to review the problem and see what assistance we could give.

The failure or improper function of a master rod bearing can and has resulted in the loss of an engine (approximately six engines in the last year) with the loss of two airplanes.

The connecting rod bearing in the Wright 1820-86 engine is cylindrical, 3.1" long and 3.3" in diameter. The ID bearing surface consists of a silver plating approximately .025" thick. The base metal is AMS 6322 - SAE 8740 steel with a Rockwell reading of C26-32 (144,000#/Sq. In.).

The R1820 master rod bearings have been a problem in determining if a satisfactory plating bond existed between the ID of the bearing steel back and the silver plate. Present methods to determine the integrity of the plating bond are: (1) shot-peening, (2) subjecting the bearing to a prescribed temperature, (3) metallographic examination, and (4) radiographic examination. The first three methods of examination only determine the condition of the bearing under study and result in destroying the bearing. An assumption is then made that bearings manufactured under the same lot number or contract are satisfactory. The use of radiographic examination, though a nondestructive method of inspection, is tedious, time-consuming, and not entirely reliable.

Since NONDESTRUCTIVE testing is under constant surveillance, in which easier and better methods are being sought, the NAVAIREWORKFAC PNCLA Management, through code 34100, was approached with the thought of using ultrasonic inspection in determining the integrity of the bond between the silver plate and the bearing, ID shell. Several samples were obtained for study.

Using an open end contract with Automation Industries, they were asked to study the problem and to determine whether the immersion ultrasonic inspection technique would be feasible.

The initial investigation into the applicability of immersion ultrasonic inspection techniques was successful. An immersed C-scanning technique was performed employing a UM 721/50W Reflectoscope with a Transigate and a 57A4006, medium focused, 3/16" diameter, 25.0 MHz transducer.

A reference standard was made up with four flat bottom holes ranging in size from 2/64" up to 8/64" terminating at the bond line. Slide #1 shows the artificially induced unbonds as recorded by the C-Scan.

Slide #2 diagrammatically illustrates the inspection technique, a pulse echo test from the OD evaluating the ID silver plating interface. A is the front surface or steel part of the bearing and C is the back surface or the silver ID of the bearing.

With the preliminary studies showing up optimistically, we arranged with the WARF in Pensacola to set up a date for a field checkout of the inspection procedure. The trip was scheduled for the week of 12 July.

Automation Industries shipped from Boulder, Colorado, an antomated C-Scan recording system consisting of a:

1. Reflectoscope - UM721.
2. Pulser/receiver - HRL.
3. Fast Transigate - Style 50C753.
4. Search Unit - 20 MHz - FM.
5. Automation Industries C-Scan System.
6. Special Rotator.

The equipment is shown in the next three slides - 3, 4, and 5.

The bearings were inspected one at a time by rotating one increment (approximately 0.010") each time the search unit traversed one axial scan over the part. The sound beam was focused at the bondline interface. Slide #6 schematically shows the inspection procedure. It takes about 15 minutes to rotate the bearing through a 360° arc. Production methods can shorten this time by adding more bearings on the rotating table.

The sensitivity was adjusted to record the signal response from the series of flat bottom test holes drilled into the bond interface in a reference sample bearing. The inspection sensitivity was set to give a 90% amplitude signal from a 2/64" diameter flat bottom hole. The recording level was adjusted to record any indications with signal amplitudes exceeding 30% amplitude.

A total of 75 new bearings issued from stock were degreased and cleaned and were inspected on site. Of the 75 new bearings inspected, 12 were found to show indication of discontinuities of varying severity.

I do not have slides for all the defects we found, but the following slides show what the defects looked like on the recording. These were, supposedly, perfect bearings (Slide #7). Metallographic examination proved the existence of the discontinuities. In Slide #8, metallographic examination showed no bond separation at the silver/steel interface; however, numerous small discontinuities were apparent along a line parallel to the bond interface approximately .001" into the silver plating. The discontinuity appeared to indicate an interrupted plating process without a deep etch prior to proceeding with the plating.

The next few slides will show some of the metallurgical analysis done by the Rocky Mountain Technology Company to prove the discontinuities picked up by the ultrasonic inspection. Sections of the rod bearings that exhibited unbonding between the steel and ID silver by ultrasonic inspection were cut, mounted, ground, polished, etched, and photographed to illustrate the microstructure of the unbonded regions.

Slide #9 - Magnification 625X - Neg. #6102

This micrograph depicts the typical appearance of the interface between the steel and the ID silver plate. The corresponding graph of the ultrasonic inspection shows the ID silver to be well bonded to the steel in this section. The steel structure appears dark, and it is shown in the top part of the micrograph. The ID silver is shown at the bottom of the micrograph. The metallograph section was cut at a right angle to the axis of the bearing and it was taken from the edge opposite the flange. In all sections the ID silver plate exhibits a thin layer adjacent to the steel. This layer appears as a bright region at the steel/silver interface in this micrograph.

Slide #10 - Magnification 625X - Neg. 6101 - S/N N-32

This micrograph shows discontinuities at the thin layer between the steel and the ID silver plate. The ultrasonic inspection graph shows a large unbonded region in this general location. Sample region is near flanged portion of bearing.

Slide #11 - Magnification 125DX - Neg #6104 - S/N N-70

Note the void between the thin layer material and the steel on this micrograph. The ultrasonic inspection graph showed numerous unbonded regions in the area where this section was taken.

Slide #12 - Magnification 500X - Neg. #6100 - S/N N-70

This section was taken opposite of the flanged side of the bearing. Many discontinuities show in the micrograph in the thin layer between the steel and the ID silver plate, and these discontinuities are in the region that exhibited unbonding by ultrasonic inspection.

Slide #13 - Magnification 500X - Neg #6099 - S/N N-77

Discontinuities are shown at the thin layer between the steel and ID silver plate. The corresponding ultrasonic inspection graph shows unbonding in this general region.

In the meantime, 100 after-service bearings were shipped to Boulder for evaluation and to determine if possible defects have existed during service in an engine and to determine if service life can be extended for the bearings. This inspection has just been completed, and I have been informed that about 17 bearings of the 100 were found to contain unbonds. Several showed severe cases of unbonding.

At the present time, we are waiting for the Supply Department in Pensacola, Norfolk, and Jacksonville, to ship out about 400 more new bearings. After these are inspected, a final report will be made on the entire project. The completion of the project will depend on the shipment of the bearings which we have been waiting for since the early part of August.

In conclusion, I would like to say that all of this came about with only a phone call. I sincerely hope that we can be of service to more of you in the future.

As soon as the report is completed, it will be mailed to you. I hope most of you have been on our distribution list. If you are not, and you would like a copy of this report, please ask and you shall receive.

REPORT OF STEERING COMMITTEE BUSINESS MEETING

The meeting was chaired by the Steering Committee Chairman, B. W. Boisvert, Kelly AFB, Texas.

Under old business, a discussion arose regarding updating the Conference's Statement of Purpose and means and extent of distribution to the membership for their comments. After considerable discussion as to overall purpose, method of soliciting comments on the Statement, and distribution, Mr. M. Budnick, U. S. Army Natick Laboratories, Natick, Massachusetts, moved that a separate document be included with the proceedings of this Conference for comments by the conferees and final reworking by the Long Range Planning Committee. Mr. C. Merhib, Army Materials & Mechanics Research Center, Watertown, Massachusetts, is to receive the comments for forwarding to the Planning Committee. The reworked Statement will then be included with next year's invitation to DOD. Acceptance, modification, or rejection can be voted on at the next Conference. The motion was accepted.

Under new business, Mr. Boisvert discussed invitations for the 21st Conference. He stated that an informal invitation was received from Nellis AFB, Nevada, and that he was awaiting a formal, i.e., written, invitation. A back-up invitation to host the Conference will be sent from Kelly AFB, Texas, in the event a formal invitation is not extended by Nellis AFB. Mr. Boisvert further stated that his installation had received a job authorization for publishing the proceedings of the next Conference.

Mr. E. Roffman, Frankford Arsenal, Philadelphia, Pennsylvania, gave a quick rundown on the functions of The Technical Cooperation Program (TTCP) and suggested that since the input for the TTCP Panel 4 has moved closer to the DOD (via several different programs) that the Analysis Report of TTCP-P4 be included in the Proceedings of the Conference. The matter was referred to the Steering Committee for its consideration.

Mr. M. Budnick offered a double motion: a. That a By-Law be included that would prohibit any voting member from serving on the Steering Committee for over 5 years (total lifetime). b. A By-Law be written that would require the Steering Committee Chairman to select and notify a nominating committee at least 90 days before the Conference. After considerable discussion, both measures were defeated.

A question was raised by Mr. J. Cipriani, Naval Air Development Center, Warminster, Pennsylvania, regarding assistance from within DOD when a problem arises. Mr. C. Merhib explained the function of the Nondestructive Testing Information Analysis Center maintained at the Army Materials & Mechanics Research Center, Watertown, Massachusetts, and informed Mr. Cipriani that he was welcome to request assistance whenever he needed it.

The meeting adjourned at approximately 1330.

Respectfully submitted
Charles P. Merhib
Recording Secretary

STEERING COMMITTEE MEMBERS

FOR THE

20TH AND 21ST NDT CONFERENCES

STEERING COMMITTEE MEMBERS

20TH DOD CONFERENCE ON NONDESTRUCTIVE TESTING

Bernard W. Boisvert, Chairman SAAMA/MMEW-4 Kelly AFB, TX 78241	Autovon: 945-7150/-7158/-7159
John G. Barr (Q3200) Frankford Arsenal Philadelphia, PA 19037	Autovon: 234-1800, Ext. 5224/7219
Truman D. Glenn (Code 135.2) Charleston Naval Shipyard Charleston, SC 29402	Autovon: 794-4517
David A. Helmich Physical Sciences Labs Bldg. 368 MAGC McClellan AFB, CA 95625	Autovon: 633-5220
John E. Lien (DCRL-QE-QT) DCASR LA 11099 So. LaCienega Blvd Los Angeles, CA 90095	Autovon: 833-1212/-1214
Larry E. Moore 62 FM/MAF/NDI McChord AFB, WA 98438	Autovon: 976-2946/-3114
Daniel Polansky Naval Ordnance Laboratory Silver Springs, MD 20904	Autovon: 233-8214/-7286
William J. Skinner (DCRC-QES) DCASR San Francisco 866 Malcolm Road Burlingame, CA 94010	Autovon: 831-3790, Ext. 434
Ira Smart (AMCQA-E) HQ Army Material Command Washington, D. C. 20315	Autovon: 227-9966

TECHNICAL CONSULTANTS
20TH CONFERENCE

RADIOGRAPHY

Mr. Emmett G. Barnes
Radiographic Section
Bldg. 908 (SMUPA-QAIQ)
Picatinny Arsenal
Dover, NJ 07801

ULTRASONICS

SGT Herbert Hansen
57 FMF/NDI
Nellis AFB, NV 89110

Mr. Stephen D. Hart
Naval Research Lab
Code 8435
Washington, D. C. 20390

Mr. Clen M. Henderson
Norfolk Naval Shipyard
Code 135
Portsmouth, VA 23709

EDDY CURRENT

Mr. Eugene Roffman
Computer Engineering Branch
Bldg. 202-1, N7000
Frankford Arsenal
Philadelphia, PA 19137

Mr. M. L. Stellabotte
Aero Materials Dept (MAMM-3)
Naval Air Development Center
Warminster, PA 18974

PENETRANTS

Mr. Richard T. Fricker
Naval Air Rework Facility
Code (344-2)
Naval Air Station
San Diego, CA 92135

Mr. Stephen E. Johnson
SMAMA/MAGCD
McClellan AFB, CA 95662

MAGNETIC PARTICLE

Mr. K. G. Wolf
Naval Air Rework Facility (96000)
Naval Air Station
Jacksonville, FL 32212

MISCELLANEOUS

Mr. Domenic J. Molella (SMUPA-RI-M)
Picatinny Arsenal
Dover, NJ 07801

PROBLEM COORDINATORS
20TH CONFERENCE

Domenic J. Molella SMUPA-RI-M ID, TSD, Bldg. 352 Picatinny Arsenal Dover, NJ 07801	Problem #1
David M. Moses DCAS-QEL Defense Supply Agency Cameron Station Alexandria, VA 22314	Problem #2
J. B. Small SMUPA-QAAS, Bldg. 61 Picatinny Arsenal Dover, NJ 07801	Problem #3 and Problem #4
David Stein SMUPA-QA-TT, Bldg. 92 Picatinny Arsenal Dover, NJ 07801	Problem #5
J. F. Erthal Aero Materials Dept. (MAMM) Naval Air Development Center Warminster, PA 18974	Problem #6

LIST OF ATTENDEES

Mr. Charles W. ANDERSON
U. S. Army Weapons Command
ATTN: AMSWE-QAE
Rock Island, IL 61201

Mr. Mahlon C. ANDERSON
27 FMJ
Cannon AFB, NM 88101

Mr. Douglas W. BALLARD
Nondestructive Testing Div.
Sandia Laboratories (AEC)
Albuquerque, NM 87115
505/264-3500

Mr. L. J. BARILLA
Code 400
Naval Air Rework Facility
Naval Air Station
Jacksonville, FL 32212
942-2149

Mr. Emmett G. BARNES
Radiographic Section
Bldg. 908 (SMUPA-QAIQ)
Picatinny Arsenal
Dover, NJ 07801
880-3964

Mr. George W. BARNETT
Naval Air Rework Facility
MCAS Cherry Point, NC 28533

Mr. John G. BARR
Frankford Arsenal
Philadelphia, PA 19137
234-1800

Mr. Norman L. BAUER
Nondestructive Testing Branch
379th FMS, SAC
Wurtsmith AFB, MI 48753
739-2011, x2307

Mr. Edward R. BEAM
DATC Code 3311
U. S. Naval Station
San Diego, CA 92136
235-2355

Mr. Roy W. BEERS
Technical Support Branch
Bldg. 150, Code 133.4
Portsmouth Naval Shipyard
Kittery, ME 03904
207/439-1000, x1722

Mr. Richard A. BERC
ADC Headquarters (DMMWP)
ENT AFB, CO 80912

Mr. Eugene L. BIRD
Code 340
Naval Air Rework Facility
Naval Air Station
Jacksonville, FL 32112
942-2164

Mr. Bernard W. BOISVERT
SAAMA/MMEW-4
Kelly AFB, TX 78241
945-7150/-7158/-7159

Mr. Peter BONVENTRE
DCASR New York
60 Hudson Street
ATTN: DCRN-QE
New York, NY 10013
212/264-9614

Mr. Ray BRACHMAN
SMUFA-N7000
U. S. Army
Frankford Arsenal
Philadelphia, PA 19137
234-1800, x22112/7171

Mr. James R. BRINK
Bldg. 19, Code 178
Naval Ship Research & Development Cen.
Washington, D. C. 20034

Mr. B. J. BRUNTY
Radiographic and Propulsion Br.
Quality Evaluation & Engr. Lab.
Code 33210
NWS Concord, CA 94520
730-1550, x2003

Mr. Richard L. BUCKELEW
AMSMI-QPA, Bldg. 4500
U. S. Army Missile Command
Redstone Arsenal, AL 35809
746-4438/-4467

Mr. Morris L. BUDNICK
U. S. Army Natick Laboratories
ATTN: AMXRE-GE
Natick, MA 01760
955-2252

Mr. Forrest C. BURNS
Army Materials Research Center
Watertown, MA 02172

MSGT James E. CANNON
347th FMS (Fabrication)
Mountain Home AFB, ID 83647

Mr. James J. CANTY
Industrial Training Branch
Army Materials & Mechanics Res.Cen.
Watertown, MA 02172
684-8344

Mr. Kenneth W. CARLSON
Construction Engr Research Lab
U. S. Army Corps of Engineering
P. O. Box 4005
Champaign, IL 61820

Mr. Mickey CASSIDY
Supervisor of Shipbuilding
Conversion & Repair
Groton, CT 06320

Mr. Terry R. CAVANAUGH
NDIL 1st FMS
MacDill AFB, FL 33608
x4313

Mr. Albert CHALFIN
FDDE LAB N7000
Frankford Arsenal
Philadelphia, PA 19137
348-6113

Mr. Joseph F. CIPRIANI
Bldg. 601, Code STH-27
Naval Air Development Center
Warminster, PA 19112
443-3496

Mr. William H. CLEARY
NDI Shop, Bldg. 714
Charleston AFB
Charleston, SC 29404
x3561

Mr. W. E. CLIFFORD
Bldg. 537
Navy Material Ind. Research Office
Philadelphia Naval Base
Philadelphia, PA 19112
443-9941

Mr. D. A. COCCIO
Naval Plant Representative
c/o Grumman Aircraft Corp.
Bethpage, L. I., NY 11714

LT Frank S. CONAWAY
MACQ, Bldg. 251
McClellan AFB, CA 95660
633-3714/-4551

Mr. Harold E. COSSIN
Service School Command
Naval Station, Box 6
San Diego, CA 92136
958-1483

Mr. Will COTTON
HQ-AFCMD/QAE
Los Angeles, CA 90045
833-1336, Comm. 643-1336

Mr. Bobby L. COTTRELL
314 TAW
314 FMSNDI
Little Rock, AR 72076
988-6143

Mr. Homer B. CURTIS
DCASR ATLANTA
ATTN: DCRA-QES
3100 Maple Drive N. E.
Atlanta, GA 30305

Mr. Evan J. DEEMER
NAVAIRSYSCOMREPLANT (ASCR-3370)
Naval Air Station
Norfolk, VA 23511
690-1197/-1198

Mr. Andrew R. DELUZIO
67th FMS, NDI LAB
Bergstrom AFB
Austin, TX 78743
685-3661

Mr. Frank DIERINGER
Space Nuclear Systems Office
Lewis Research Center (MS-501-1)
21000 Brookpark Rd.
Cleveland, OH 44126
216/433-6821

Mr. E. L. DONALDSON
Code 320
Naval Air Rework Facility
Naval Air Station
Jacksonville, FL 32212
942-2738

Mr. Ed DOUGHERTY
Frankford Arsenal
ATTN: F4000
Philadelphia, PA 19137
x6369

Mr. George DRUCKER
Radiographic Section, Bldg. 908
ATTN: SMUPA-AQ-I-Q
Picatinny Arsenal
Dover, NJ 07801
880-3964

Mr. John F. ERTHAL
Aero Materials Dept. (MAMM)
Naval Air Development Center
Warminster, PA 18974
215/672-9000, x2809

Mr. Norbert H. FAHEY
Quality Assurance Br.
Army Materials & Mechanics Res. Cen.
Watertown, MA 02172
684-8466/-8464

Mr. John J. FISCELLA
ATTN: SWEWV-QAM
Watervliet Arsenal
Watervliet, NY 12189
974-5007

Mr. Ken FIZER
Naval Air Rework Facility (341)
Naval Air Station
Norfolk, VA 23511
690-8811, Comm. 444-8811

CAPT Richard L. FORSYTHE
AF Plant #6
Marietta, GA 30060
424-4228

Mr. Herbert FRANKEL
Unit 4 Benet Lab.
Watervliet Arsenal
Watervliet, NY 12189

Mr. Richard T. FRICKER
Naval Air Rework Facility (344-2)
Naval Air Station
San Diego, CA 92135
958-6711

Mr. Richard J. FRISINA
FRL, PYRO, Bldg. 1515
Picatinny Arsenal
Dover, NJ 07801
880-2429

Mr. Elvin L. FRITZ
Code 341, Bldg. 44
Naval Air Rework Facility
Naval Air Station
Alameda, CA 94501
686-4559/-4137

Mr. James W. GALE
PM-MEP-PATA
Fort Belvoir
7500 Backlick Road
Springfield, VA 22314
354-4506

Mr. Truman D. GLENN
Charleston Naval Shipyard
Code 135.2, Bldg. 13
Charleston, SC 29408
794-4517

Mr. J. C. GOODWIN, Jr.
Navl Plant Branch Rep. Office
Hercules, Incorporated
P. O. Box 157
Magna, UT 84044
801/297-5911, x2712

LT Dee L. GRABER
67th Field Maintenance Squadron
Bergstrom AFB, TX 78743
685-2294

Mr. Ted GREENHALGH
OOAMA, Hill AFB, UT 84401
ATTN: MMEDW
829-6636

Mr. Lee R. GULLEY
Air Force Materials Lab./LAA
Wright-Patterson AFB, OH 45433
785-5108

Mr. Henry M. GUNDERSEN
Code 340
Naval Air Rework Facility
Naval Air Station
Jacksonville, FL 32212
942-2164

Mr. Duane GUSTAD
Frankford Arsenal
Bridge & Tacony Streets
ATTN: 74100
Philadelphia, PA 19137
234-1400, x23023

Mr. Brant HACKMANN
AFLC HQ
Maintenance Technology Div.
Bldg. 166
Wright Patterson AFB, OH 45433
x76164

Mr. Charles E. HAIRE
DCASO Miami (Branch 2)
P. O. Box 23548
Oakland Park, FL 33307
Comm. 565-2749

Mr. Michael HALIK
Adv. Proc. Technical Div.
MTD (SMUPA-MT-T)
Picatinny Arsenal
Dover, NJ 07801
328-4504

Mr. Jerome HALL
Code EAD
U. S. Naval Weapons Laboratory
Dahlgren, VA 22448
249-8411

SGT Herbert HANSEN
57 FMF/NDI
Nellis AFB, NV 89110
x4508

SGT R. K. HARDIMAN
NDI Spec. Lab.
313 FMS, Bldg. 662
Forbes AFB, KA 66620

Mr. Stephen D. HART
Naval Research Lab. (Code 8435)
Washington, D. C. 20390
297-3613

Mr. Samuel HELF
Explosives Division, Bldg. 407
Picatinny Arsenal
Dover, NJ 07801
880-2581

Mr. D. A. HELMICH
Physical Sciences Labs
Bldg. 368 MAGC
McClellan Field, CA 95625
633-5220

Mr. Clen M. HENDERSON
Norfolk Naval Shipyard (Code 135)
Portsmouth, VA 23709
961-5495

Mr. Robert H. HENDRICKS
DCASR
Cleveland
F.O.B.
1240 East 9th Street
Cleveland, OH 44199
ATTN: DCRO-QE
580-5209

CAPT Glen H. HILL
GQ ATC/LGMAT
Randolph AFB, TX 78148
487-4546/-2981

Mr. Earl L. HOWARD
U. S. Army Bell Plant Activity
P. O. Box 1605
Fort Worth, TX 76101
733-3740

Mr. Burleigh HUMPHREY
Naval Plant Rep. Office
Director of Engineering
Napier Field
Dothan, AL 36301
558-1110

Mr. Foy L. HUNTER
63 FMS
Norton AFB, CA 92409
862-3609

Mr. V. C. JACKSON
UCC-Y-12 (AEC)
Building 9723-14
Oak Ridge, TN 37830

Mr. Murray M JACOBSON
AMMRC
Arsenal Street
Watertown, MA 02172
684-8408

Mr. Michael T. JAMGOCHIAN
Supervisor of Shipbldg (C&R)
Newport News, VA 23607

Mr. Harry P. JOHN
DCASR Philadelphia (QA)
2800 S. 20th Street
Philadelphia, PA 19145
ATTN: QES.8
444-3463

Mr. Stephen E. JOHNSON
SMAMA/MAGCD
McClellan AFB, CA 95662
633-4928

Mr. Robert O. JOYCE
DCASR Chicago
P. O. Box 66475, O'Hare Int'l Airport
Chicago, IL 60666

Mr. William A. KENDALL
449 FMS-NDI
Kinchdoe AFB, MI 49788
x 2316

AMSC J. A. KIDWELL
NDI School, Bldg. 520
NATTC, Jacksonville, FL 32212
942-3324

Mr. Alfred S. KRESS
U.S. Army Tank Automotive Command
AMSTA-Q
Warren, MI 48090
313/264-1100, x2531

Mr. George KRESTALUDE
Naval Air Rework Facility (310)
Naval Air Station
Jacksonville, FL 32212
942-2620

Mr. R. L. KRILOWICZ
Quality Assurance Engineering
Room 1276, Bldg. CCF-9
General Electric - AFPRO
Valley Forge, PA 19481

Mr. W. W. LAKE
Director of Product Assurance
12th & Spruce
U.S. Army Aviation Sys. Command
St. Louis, MO 63102
698-5726/-5727

CDR James G. LANG
CO MIO/COTP
P. O. Box 4389
Jacksonville, FL 32201
981-2648

Mr. Harvel T. LAWSON
Environmental & Metrology Test
Building 8716
Army Missile Command
Redstone Arsenal, AL 35802

Mr. John E. LIEN
DCASR LA
ATTN: DCRL-QE QT
11099 So. LA Cienega
Los Angeles, CA 90095
833-1212/-1214

Mr. Joe H. LOPEZ
NDI Lab
DMMFFI
Kirtland AFB
Alburquerque, NM 87117

Mr. Alfred C. MALCHIODI
Supervisor of Shipbuilding
Conversion and Repair
Groton, CT 06320

Mr. Ezeo E. MARKINE
AFPRO North American Rockwell
L.A. Division Det. 15
Production Division
Aviation & Imperial
Los Angeles, CA 90050

Mr. Ed MATZKANIN
Physical Test Section
Bldg. 3520, K.F.R.
Yuma Proving Ground
Yuma, AZ 85364
727-6661/-6718

Mr. Ray J. McGOWAN
DCASD-CA
Defense Supply Agency
8900 DeSoto Avenue
Canoga Park, CA 91304

Mr. Bruce J. McGREGOR
Naval Air Rework Facility(BR.7100)
NAS Norfolk, VA 23511

Mr. Charles P. MERHIB
Army Mechanics & Materials
Research Center
Watertown, MA 02172
684-8343/-8552

Mr. Domenic J. MOLELLA
SMUPA-RI-M
ID, TSD, Bldg. 352
Picatinny Arsenal
Dover, NJ 07801
880-3355

Mr. Larry MOORE
62 FM/MAF/NDI
McChord AFB, WA 98438
976-2946/-3114

Mr. Richard MORGAN
Naval Air Station (AIMD QA)
Jacksonville, FL 32212
942-3055

Mr. David M. MOSES
DCAS-QEL
Defense Supply Agency
Cameron Station
Alexandria, VA 22314

Mr. Clyde W. NAGEL
Naval Air Rework Facility
Quonset Point, RI 02819

Mr. Robert T. NIEMEYER
Harry Diamond Labs
Conn. Ave. & Van Ness St.
Washington, D. C. 20438
Room 105, Bldg. 92
286-9746

Mr. Robert S. NORTE
Naval Air Systems Command (AIR-4117B)
Washington, D. C. 20360
289-1349/-1318

Mr. Milton S. ORYSH
Naval Ship Engineering Center
NAVSECPHILADIV
Philadelphia, PA 19112
443-3922

Mr. Richard D. OVERLEY
White Sands Missile Range, NM 88002
STEWS-TE-AC
258-5632

Mr. J. M. PATE
317th FMS
Pope AFB, NC 28308
394-2659

Mr. John PAULL
NAVSHIPS Test Examiner
Certification Agency
Service School Command
Box 6, Naval Station
San diego, CA 92136
958-1483

Mr. Phillip E. PAYNE
Chief of Naval Air Training (4121)
Naval Air Station
Pensacola, FL 32509
922-3396/-3397/-3398

Mr. H. Shannon PHILLIPS
DCASR Dallas
Technical Support Division
500 South Ervoy Street
Dallas, TX 75201
940-1465

Mr. Daniel POLANSKY
Naval Ordnance Lab
Silver Springs, MD 20904

Mr. Raymond C. PURCELL
Naval Air Rework Facility (341)
Naval Air Station, Bldg. 741
Pensacola, FL 32508
922-3551

Mr. Norman C. REID
AFPRO Lockheed - GA Co.
QAE Division
Marietta, GA 30060

Mr. John H. REPP
Naval Air Rework Facility (340)
Naval Air Station
Jacksonville, FL 32212
942-2164

MSGT Clyde RICHARDSON
Chief of Maintenance
ATTN: 60 FMS MAF (NDI)
Travis AFB, CA 94535

Mr. Gene V. RICHISON
Code 4533
USNWC China Lake, CA 93555
714/939-4233

Mr. Orville W. ROBINSON
c/o NDI LAB
Davis Mothan AFB
Tucson, AZ 85707
661-4477, Comm. 793-4477

Mr. Robert L. RODGERS
Eustis Directorate
U.S. Army Air Mobility R&D LAB
SAVOL-EU-ST
Fort Eustis, VA 23604
729-4304/-5732

Mr. Eugene ROFFMAN
Computer Engineering Branch
Bldg. 202-1, N7000
Frankford Arsenal
Philadelphia, PA 19137
348-5512

Mr. Albert P. ROGEL
Materials Engineering
Bldg. 250G NMET
McClellan AFB, CA 95652
633-6200

Mr. Anthony J. SAPONARO
USA CDC MA
CDCMA-E
Aberdeen Proving Ground, MD 21005
870-278-5218

Mr. Donald E. SCHEIN
DCASR St. Louis
1136 Washington Ave.
ATTN: DCRS-AE
St. Louis, MO 63101
298-6095

Mr. Paul SCHINDLER
Picatinny Arsenal
ATTN: SMUPA-AD-M
Dover, NJ 07801
880-3470

Mr. William H. SCHOELLER
Picatinny Arsenal
ATTN: SMUPA-RI-M
T.S.D. Bldg. 352
Dover, NJ 07801
880-4145

Mr. George J. SCHULTZ
Engineering Division
NAVAIRSYSCOMREPLANT
Norfolk, VA 23511
690-3609

AMS2 Harold H. SEGAR
AIMD NDI LAB
Hangar 1000
Naval Air Station
Jacksonville, FL 32212

Mr. George W. SEVALL, Jr.
Construction Engr Research Lab
P. O. Box 4005
Champaign, IL 61820
217/352-6511, x 501

Mr. Harry SHAPIRO
Code 228, Bldg. 537-2
NAVMIRO
Philadelphia, PA 19112
443-3992

Mr. Ronald E. SHARPE
Physical Properties Lab
WRAMA/MAGCP, Bldg. 165
Robins AFB, GA 31093
468-5887/-4097

Mr. Donald G. SHIFLER
SUPSHIP C&R
Supervisor of Shipbuilding
Conversion and Repair
USN Newport News, GA 23607

TSGT Charles M. SITTENAUER
HQ ATC/LGMAT
Randolph AFB, TX 78148
487-4546

Mr. J. B. SMALL
SMUPA-QAAS, Bldg. 61
Picatinny Arsenal
Dover, NJ 07801
880-4133

Mr. John A. SMALLEY
DCASD Orlando
Bennington Bldg.
3335 Maguire Blvd
Orlando, FL 32813

Mr. Ira SMART
Director of Quality Assurance
HQ U. S. Army Material Command
ATTN: AMCQA-E
Washington, D. C. 20315
227-9966

Mr. Michael I. SPECIALE
1001st Field Maint. Squadron
Andrews AFB, MD 20331
585-5607

Carol E. SPRINGER
Ballistics Division
Naval Weapons Laboratory
Dahlgren, VA 22448
249-8026

Mr. Charles R. STANLEY
Naval Air Rework Facility (Code 340)
Naval Air Station
Jacksonville, FL 32212
942-2164

Mr. David STEIN
SMUPA-QA-TT, Bldg. 92
Picatinny Arsenal
Dover, NJ 07801
880-2123

Mr. M. L. STELLABOTTE
Aero Materials Dept. (MAMM-3)
Naval Air Development Center
Warminster, PA 18974
441-2809

Mr. Jay STEVENS
NDT Coordinator (AIR-52055)
Naval Air Systems Command
Washington, D. C. 20360
222-7594

Mr. George F. STEWART
Naval Safety Center (Code 1211)
Naval Air Station
Norfolk, VA 23511
624-7926

SSGT Vincent M. STEWART
122-1 Shawnee Drive
Minot AFB, ND 58701

Mr. Fred W. THOMAS
Naval Air Rework Facility(340)
Naval Air Station
Jacksonville, FL 32212
942-2164

Mr. J. T. THORNHILL
NDT Personnel Certification Sec.
Bldg. 13, Code 134.22
Charleston Naval Shipyard
Charleston, SC 29408
466-2890

Dr. N. W. TIDESWELL
Naval Ship R&D Center (Code 2283)
Annapolis, MD 21401
Comm. 218-771, x 8429

Mr. Walter B. TRIPLETT
AMSMI-QLC, Bldg. 4500
Redstone Arsenal, AL 35809

Mr. Arthur A. TRYKOWSKI
Q.A. Directorate
DCASR Cleveland
23555 Euclid Avenue
Cleveland, OH 44117
216/383-2960

Mr. John G. TURBITT
Quality Eval. & Engr Lab (312)
Naval Torpedo Station
Keyport, WA 98345
744-2501

Mr. Robert P. TURNER, Jr.
Eglin AFB, FL 32544
ATTN: FID-9
884-9417/-9122

Mr. Max R. TURVEY
Commander Naval Air Force
U. S. Pacific Fleet
NAS North Island
San Diego, CA 92135

Mr. Jim W. TWEEDDALE
Quality Verification Div (420)
Naval Air Rework Facility
Naval Air Station
Jacksonville, FL 32212
942-2305

Eleanor TH. VADALA
Aero Materials Dept (MAPC-1)
Naval Air Development Center
Warminster, PA 18944
441-2818

Mr. Robert H. WALLACE
Myrtle Beach AFB, SC 29577
448-8311

Mr. James C. WAUFORD
DCASD Dayton
Quality Assurance Division
c/o DESC, Wilmington Ave.
Dayton, OH 45401
898-6953

Mr. Mark H. WEINBERG
SMUPA-QA-A-R, Bldg. 94
Picatinny Arsenal
Dover, NJ 07801
880-5646

Mr. John R. WILLIAMSON
AFML/LTF
Wright-Patterson AFB, OH 45433
785-2702/-2871

Mr. Frank WILSON
Electronics Command
Production Assurance Directorate
AMSEL-PA-E
Fort Monmouth, NJ 07703

Mr. K. G. WOLF
Naval Air Rework Facility (96000)
Naval Air Station
Jacksonville, FL 32212
942-2103

Mr. Jack E. WOLLETT
Quality Assurance Div.(DCSC-SQP)
Defense Construction Supply Center
Columbus, OH 43216
855-2723

Mr. Fred WORLEY
3525th PTWG
3525th FMS Squadron - NDI LAB
Williams AFB, AZ 85224
474-2360

UNCLASSIFIED
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Naval Air Rework Facility, Jacksonville, Florida	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b. GROUP

3. REPORT TITLE
20TH DOD CONFERENCE ON NONDESTRUCTIVE TESTING

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)
Final report of meeting held 10-12 November 1971

5. AUTHOR(S) (First name, middle initial, last name)
Bernard W. Boisvert, SAAMA, Kelly AFB, TX
Henry M. Gundersen, NAVAIREWORKFAC JAX

6. REPORT DATE	7a. TOTAL NO OF PAGES	7b. NO OF REFS
30 March 1972	376	None

8a. CONTRACT OR GRANT NO None	9a. ORIGINATOR'S REPORT NUMBER(S) None
b. PROJECT NO None	
c. None	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) None
d. None	

10. DISTRIBUTION STATEMENT
Each transmittal of this document outside the Department of Defense must have prior approval of Naval Air Rework Facility, Jacksonville, Florida.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
None	Naval Air Rework Facility Naval Air Station Jacksonville, Florida 32212

13. ABSTRACT

Approximately annually, since 1951, the Department of Defense has held a conference on nondestructive testing. These meetings are open only to civil service and military personnel and to selected guests invited by the Conference Steering Committee.

This document is a compilation of the six problems presented for discussion among the attendees. In addition, fourteen technical papers were presented which described work underway or recently completed at the presenter's facility.

This document will be of value principally to those who attended the conference and to those who need a current list of active personnel in the field of nondestructive testing. The conference was organized by the Steering Committee for the 20th Conference, and was hosted on 10-12 November 1971 by the Naval Air Rework Facility, Jacksonville, Florida.

UNCLASSIFIED
Security Classification

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
ALUMINUM ALLOYS						
BOILER TUBES						
NONDESTRUCTIVE TESTING						
BOMB BODY						
ARTILLERY PROJECTILE						
FATIGUE CRACKS						
JET ENGINE BLADE						
MISSILE WARHEAD						
FRICTION WELDS						
INFRARED SPECTROSCOPY						
COMPUTER						
NEUTRON SOURCES						
NEUCLEAR TRACK						
HIGH SPEED TESTING						
ORGANIC COMPOSITE						
STEREORADIOGRAPHY						
GUN TUBE						
CRACK DETECTOR						
PYROTECHNIC COMPOSITIONS						
BOND INSPECTION						

DD FORM 1 NOV 65 1473 (BACK)

UNCLASSIFIED
Security Classification